Habitat Limiting Factors and Reconnaissance Assessment Report

Executive Summary

Green/Duwamish and Central Puget Sound Watersheds

(Water Resource Inventory Area 9 and Vashon Island)

KING COUNTY

Washington State Conservation Commission

December 2000

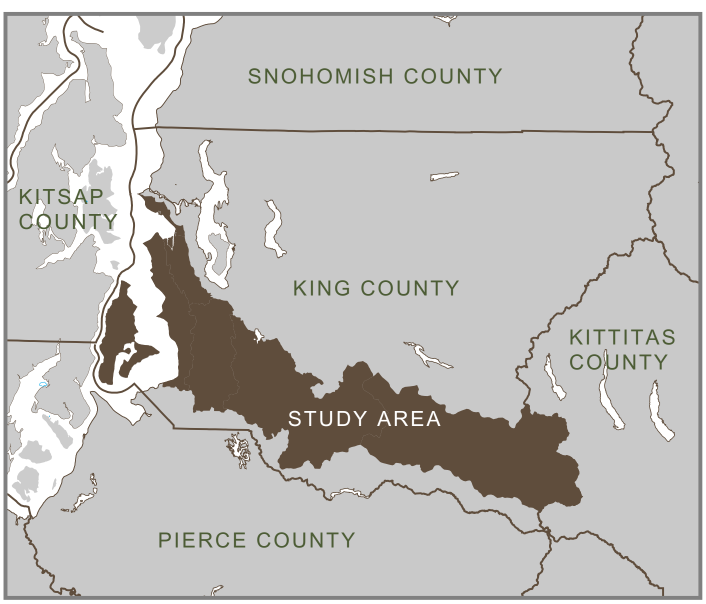
I. INTRODUCTION

Many stocks of the wild salmonid populations in the Puget Sound ecoregion have declined. In March 1999, the National Marine Fisheries Service (NMFS) listed Puget Sound chinook salmon as a Threatened species under the Endangered Species Act (ESA). In November 1999, the U.S. Fish and Wildlife Service (USFWS) listed bull trout as a Threatened species under the ESA. Other populations and species are under consideration for listing as Threatened or Endangered under ESA.

The Habitat Limiting Factors and Reconnaissance Report

As a first step in the long-term commitment to salmonid recovery in Water Resource Inventory Area 9 (WRIA 9) and Vashon-Maury Islands, staff and representatives from the Washington Conservation Commission and the WRIA 9 Steering Committee worked together to develop the Habitat Limiting Factors and Reconnaissance Assessment Report. The purpose of this report is to provide a current snapshot in time of the existing salmonid species and the habitat conditions that limit the natural production of salmonids in the Green/Duwamish River watershed, the independent drainages to Puget Sound from Elliott Bay south to the Puyallup watershed, the drainages on Vashon-Maury Islands, and the nearshore. This area is collectively termed WRIA˚9 for the purposes of this report. This report:

- Provides a summary of what is known about current and past salmonid species and habitat conditions in the WRIA for future reference;
- Provides baseline information for the WRIA (based on currently available data) for use in the implementation of an adaptive management program;
- Identifies habitat limiting factors in the WRIA, key findings, and associated data gaps that will be used to build the WRIA 9 Salmonid Conservation Plan; and
- Provides preliminary guidance for policy makers to determine next steps and direct resources for the recovery process.



Focus on Habitat Limiting Factors

While the causes of declining salmonid populations can be attributed to many factors, this report focuses on human-controlled modification or destruction of saltwater nearshore and freshwater habitats and the changes to ecological processes that affect those habitats in WRIA 9.

Physical Description

The Green/Duwamish River is the largest freshwater component of WRIA 9. The Green/Duwamish mainstem is responsible for producing the eight major species of anadromous and resident salmonids present in the watershed. The Green/Duwamish River watershed begins in the Cascade Mountains about 30 miles northeast of Mount Rainier and flows for over 93 miles to Puget Sound at Elliott Bay in Seattle. It is bounded on the north by the Lake Washington watershed (WRIA 8) and to the south by the Puyallup watershed (WRIA 10). Historically, the White, Green, and Cedar (via the Black) Rivers flowed into the Duwamish River, and the system drained an area of over 1,600 square miles. Because of the diversion of the White River in 1911 and the Cedar River in 1916, the Green/Duwamish drainage area has been reduced to 556 square miles.

To help us better understand the Green/Duwamish watershed and WRIA 9, we have divided it into six geographic areas as shown in the corresponding map (see centerfold map on pages 8-9):

- Upper Green River Sub-watershed (River Mile 64.5 to 93+, Howard Hanson Dam to headwaters)
- Middle Green River Sub-watershed (River Mile 32.0 to 64.5, Highway 18 to Howard Hanson Dam)
- Lower Green River Sub-watershed (River Mile 11.0 to 32.0, Black River to Highway 18)
- Green/Duwamish River Estuary Sub-watershed (River Mile 0.0 to 11.0, Elliott Bay/Harbor Island to Black River)
- Nearshore Sub-watershed (independent tributaries to Puget Sound and Vashon-Maury Islands)
- Nearshore Sub-watershed (estuarine/marine waters and habitats)

These divisions make sense because of natural and/or anthropogenic landscape features. However, the sub-watersheds are all linked together as part of the larger ecosystem and by the processes necessary to support naturally produced salmonids.

Land Uses and History

Land uses differ considerably across the watershed and there are few watersheds in the Puget Sound basin that match the extremes evident in WRIA 9. In the Upper Green River Sub-watershed, land is devoted almost entirely to forest production. The Middle Green River Sub-watershed is characterized by a mix of residential, commercial forestry, and agricultural land uses. Residential, industrial, and commercial uses prevail in the Lower Green River Sub-watershed. The Green/Duwamish River Sub-watershed is split between residential and industrial uses. Independent tributaries to Puget Sound, including Vashon-Maury Islands, are primarily residential with small areas of commercial development and mining.

These land uses have emerged over the last 150 years, which have seen a number of other fundamental changes to the WRIA. Some of these major historical changes include:

- 1851 European settlement begins in the Duwamish River.
- 1880-1910 Logging occurs across much of the watershed and in the lower river valley; agricultural land use expands.
- 1911 White River is diverted from Green River to Puyallup River for flood control, reducing watershed area by 30 percent.
- 1913 City of Tacoma begins diverting water from Green River to provide water for homes and industry. Anadromous salmonids are blocked from Upper Green River Sub-watershed.
- 1916 Black and Cedar Rivers are diverted from Duwamish River to Lake Washington to improve navigation, further reducing watershed area by 40 percent from its original size.

- 1900-1940 Duwamish estuary tidelands are filled, drained, and dredged to support growing industrial and port activities.
- 1895-1980 The Green/Duwamish River is channelized and diked for navigation and flood control.
- 1945-2000 Residential, commercial, and industrial land uses expand, largely replacing farmlands and forests in the western half of the WRIA.
- 1962 Howard Hanson Dam is completed for flood control purposes.

Fish Status

Every species of anadromous salmonid that is native to the west coast of North America (coho, chinook, chum, sockeye, and pink salmon and coastal cutthroat, steelhead, and bull trout/Dolly Varden char) as well as one non-native (Atlantic salmon) recently have been found in the Green/Duwamish watershed.

During the period 1968-1997, the Green/Duwamish River supported an average yearly total run (fish returning to the river and those caught in the fisheries) of about 41,000 adult chinook salmon. It has been estimated that on average 5,700 chinook annually returned to the river to spawn naturally and 8,200 returned to the Soos Creek hatchery during the same time interval (Figure˚1). The Green River has not experienced the same decline in naturally spawning adult chinook that has occurred in other Puget Sound streams but these numbers may be masked by a high hatchery chinook stray rate onto the spawning grounds. Research is needed to better understand the contribution of strays to the wild chinook stocks in the Green/Duwamish watershed.

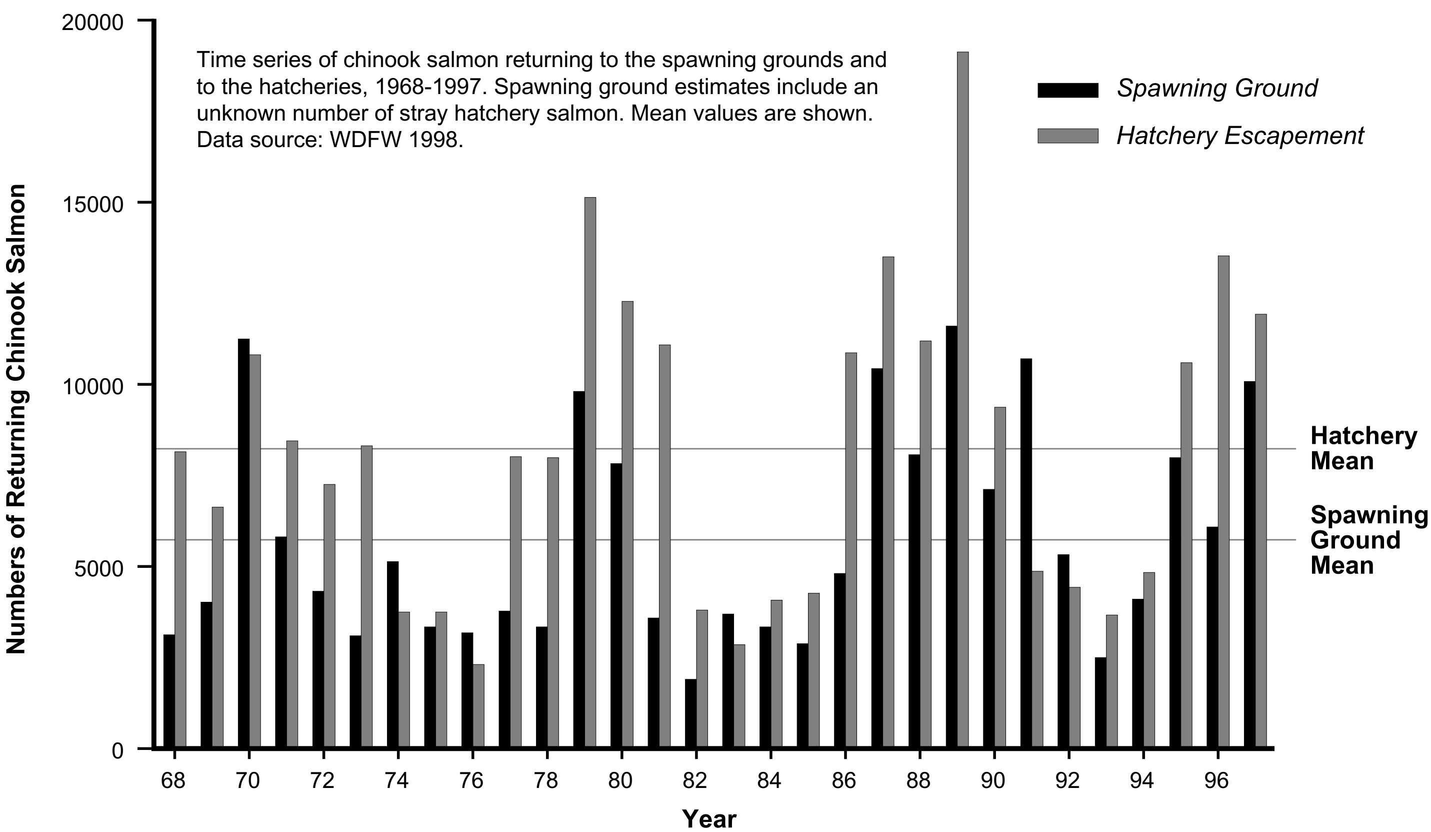


Figure 1
Returning Chinook Salmon to the Spawning Grounds and Hatcheries 1968-1997

III. INDIVIDUAL SUB-WATERSHED SYNOPSES

Upper Green River Sub-watershed
(RM 64.5 to headwaters)

Human population: 1

Primary designated land uses: forest production (nearly 100˚percent), municipal water supply, and recreation

Mean annual flow: about 1,300 cubic feet per second at River Mile 64.5

Recently documented salmonid species present: resident coastal cutthroat, transported juvenile steelhead, transported juvenile chinook, transported juvenile coho, and transported steelhead adults

Additional salmonid fish species historically present: chinook, coho, and bull trout (possible but not likely)

Anadromous fish access to the upper reaches of the Green/Duwamish River has been blocked at River Mile (RM) 61 since 1911 when the City of Tacoma started construction on a water diversion dam (Headworks). While the City of Tacoma has limited public access in a portion of the upper sub-watershed to protect the potable water supply, commercial timber harvest has occurred throughout this portion of the watershed. This activity has altered many of the ecological processes and degraded much of the habitat. Roads and a railroad also have had an impact on the mainstem as described below. Currently, only the resident form of coastal cutthroat and some anadromous salmonids that have been transported around the dams (juvenile steelhead trout, chinook and coho salmon, and adult winter steelhead trout) use this portion of the watershed.

In 1962, Howard Hanson Dam (HHD), a flood control dam, was completed at RM 64.5, which is the downstream boundary of this sub-watershed. HHD also is a complete barrier to upstream and downstream adult migration. The large flood control dam and associated reservoir interrupts the natural flow of sediments and large woody debris to lower mainstem reaches of the Green River. It also chronically floods upstream habitat.

Habitat Limiting Factors and Impacts

Mainstem Green River:

While the two dams block upstream passage and severely hamper downstream passage, some salmonids do reside in this reach and are affected by existing habitat conditions. If passage is improved in the future, existing habitat conditions will affect salmonids that are reintroduced to the area. These limiting habitat factors include:

The placement of roads and a railroad immediately adjacent to rivers and streams resulting in:

- Reduction and degradation of riparian habitat functions such as shade and large woody debris; and
- Limited lateral channel migration and limited creation of new habitat.

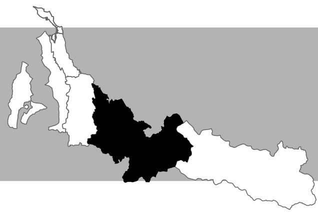
A reservoir pool that is:

- Reducing spawning habitat and riparian functions due to periodic inundation of 4.5 miles of the Green River mainstem and 3.0 miles of tributaries; and
- Delaying juvenile outmigration.

Tributaries:

Logging practices resulting in:

- Reduced riparian habitat functions such as shade and instream large woody debris;
- Fish passage barriers;
- Excessive sedimentation, especially of fine sediments;
- Decreased water quality; and
- Altered stream hydrology.



Middle Green River Sub-watershed
(RM 32.0 to 64.5)

Human population: 112,000

Primary designated land uses: residential (50 percent), commercial forestry (27 percent), agriculture (12 percent)

Mean annual flow: 1,300 to 2,000 cubic feet per second

Recently documented salmonid species present: chinook, coho, chum, pink, sockeye, steelhead, coastal cutthroat trout, and occasionally Atlantic salmon

Additional salmonid fish species historically present: bull trout (possible but not likely)

In the Middle Green River Sub-watershed (RM 64.5 to 32.0), the construction and operation of Howard Hanson Dam has reduced the recruitment of sediments to a level where the river is in places gravel-starved and incising. Because HHD serves to limit floods, the natural flow regime of the mainstem Geen River has been altered, harming habitat as described below. The Tacoma Headworks also block upstream passage of all salmonids. Currently chinook, steelhead, coastal cutthroat, coho, and chum utilize this reach up to the Headworks for spawning and rearing. There are limited numbers of pink and sockeye salmon as well an occasional observation of Atlantic salmon adults. All species, with the exception of Atlantic salmon, use this reach of the mainstem for migration and feeding.

Habitat Limiting Factors and Impacts

Mainstem Green River:

Dams, revetments, and residential and agricultural land uses that are:

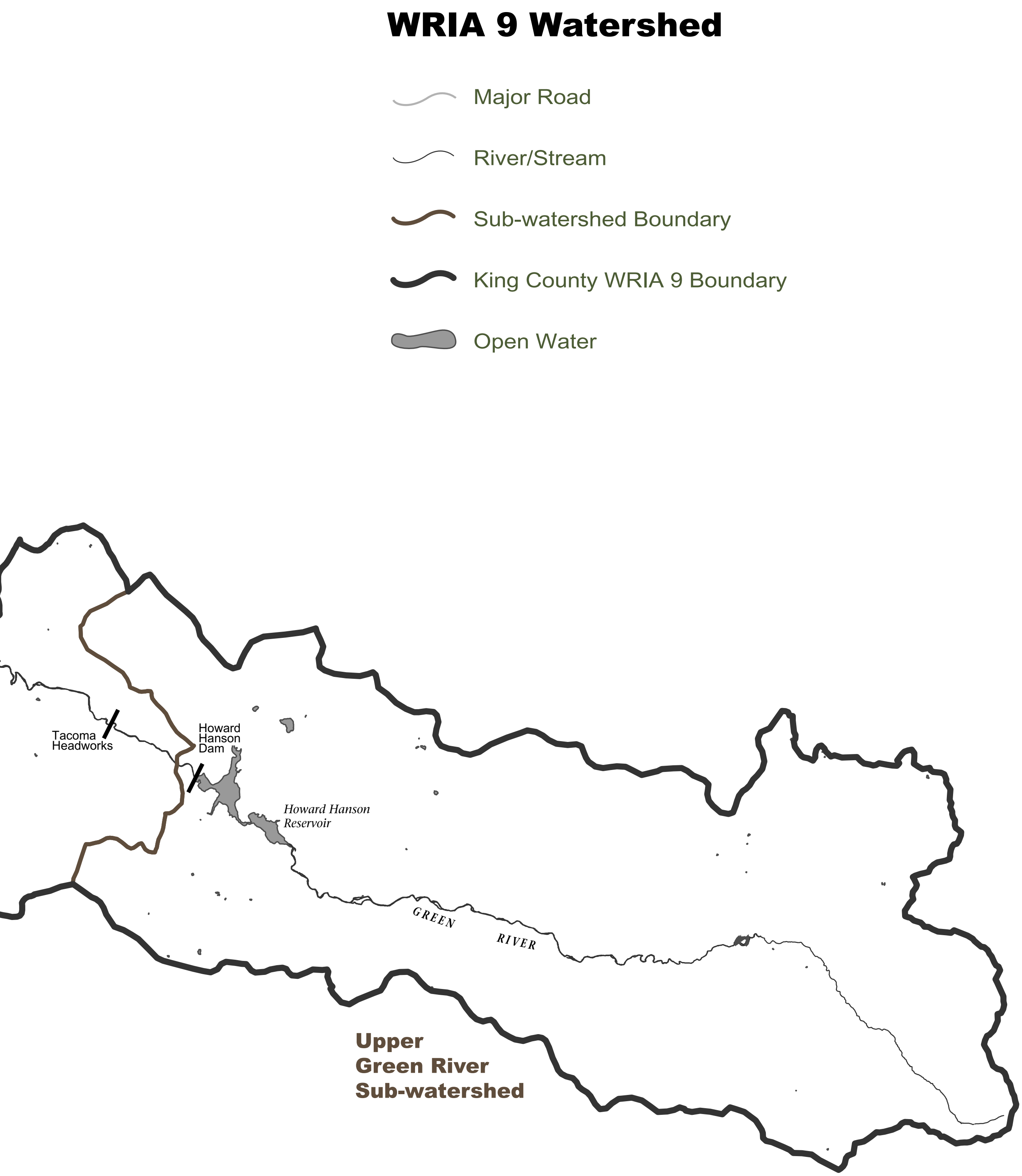
- Changing the natural flow regime in ways that have harmed salmonids;
- Causing gravel starvation and scouring;
- Reducing the amount and size of large woody debris with a consequent reduction of channel complexity;
- Reducing side-channel and other off-channel habitats; and
- Reducing and degrading riparian habitat functions.

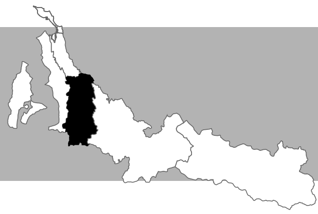
Tributaries:

Residential, agricultural, and some urban development that are:

- Reducing and degrading wetland and riparian functions;
- Reducing forest cover and increasing impervious surfaces leading to hydrologic disruption to stream flow, channel degradation, increased sedimentation, and decreased water quality;
- Rechanneling streams and limiting their lateral migration to facilitate roads and protect property;
- Reducing the amount and size of large woody debris;
- Creating barriers to fish passage; and
- Introducing non-native plant and animal species.

Nearshore
Sub-watershed
Elliott Bay
SEATTLE
Green/Duwamish
Estuary Sub-watershed
Duwamish River
SEATTLE
99
Puget Sound
5
900
509
TUKWILA
BURIEN
405
RENTON
Vashon Island
NORMANDY PARK
SEATAC
167
515
Maury Island
DES MOINES
KENT
COVINGTON
MAPLE VALLEY
516
99
5
FEDERAL WAY
167
AUBURN
Lake Sawyer
Soos Creek
BLACK DIAMOND
18
164
ALGONA
GREEN RIVER
169
Newaukum Creek
ENUMCLAW
Vashon
Sub-watershed
Nearshore
Sub-watershed
Lower
Green River
Sub-watershed
Middle
Green River
Sub-watershed
N
0
2
4
6 Miles
April 2000


WRIA 9 Watershed
Major Road
River/Stream
Sub-watershed Boundary
King County WRIA 9 Boundary
Open Water
Tacoma Headworks
Howard Hanson Dam
Howard Hanson Reservoir
GREEN RIVER
Upper Green River Sub-watershed



Lower Green River Sub-watershed
(RM 11.0 to 32.0)

Human population: 154,000

Primary designated land uses: residential (50 percent), industrial (17 percent), and commercial (10 percent)

Mean annual discharge: over 2,000 cubic feet per second

Recently documented salmonid species present: chinook, coho, chum, pink, sockeye, steelhead, coastal cutthroat trout, and occasionally Atlantic salmon

Additional salmonid fish species historically present: bull trout (possible but not likely)

In the Lower Green River Sub-watershed (RM 32.0 to 11.0), the diversion of the White River in 1911 has led to a decrease in flow and sediment and a lowering of the floodplain. Howard Hanson Dam operations and water withdrawal at the Tacoma Headworks have led to an unnatural flow regime (reduction in flood flows and lower summer flows). One of the most significant habitat alterations has been the construction of a series of revetments that has resulted in the disconnection of off- and side-channel habitats such as sloughs and adjacent wetlands. Currently this reach is utilized for the upstream and downstream migration and rearing for all native anadromous salmonid species. It provides some chinook, pink, sockeye, and chum salmon and steelhead spawning habitat.

Habitat Limiting Factors and Impacts

Mainstem Green River:

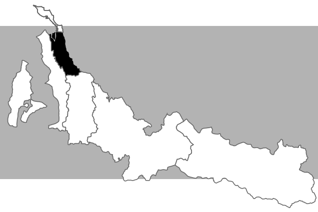
Urbanization, water diversions, and revetments that are:

- Lowering the floodplain and disconnecting off-channel habitats such as sloughs and adjacent wetlands;
- Reducing large woody debris and associated instream complexity, such as pools and riffles;
- Creating some adult salmon migration problems due to low flows;
- Causing chronic water quality problems; and
- Severely reducing riparian habitats and associated functions.

Tributaries:

Intense urbanization and infrastructure that are:

- Reducing forest cover and increasing impervious surfaces leading to hydrologic disruptions to stream flow, channel degradation, increased sedimentation, and decreased water quality;
- Channelizing streams to facilitate land use practices;
- Creating barriers to fish passage; and
- Introducing non-native plant and animal species.



Green/Duwamish Estuary Sub-watershed
(RM 0.0 to 11.0)

Human population: 58,000

Primary designated land uses: industrial (43 percent) and residential (39 percent)

Mean annual discharge: tidally influenced reach although more than 2,000 cubic feet per second of freshwater

Recently documented salmonid species present: chinook, coho, chum, pink, sockeye, steelhead, coastal cutthroat, adult bull trout/Dolly Varden char, and occasionally Atlantic salmon

The Duwamish River is that portion of the Green River downstream of the historic confluence with the Black River. With the diversion of the Cedar River in 1916, the Black River was left almost dry. Today, the only flow in the Black River comes from the tributary streams that drain from the eastern bluffs of the lower Green River valley.

The urbanization and industrialization of this portion of the Green River watershed has resulted in an extensive system of filled tidelands and flood control revetments that have eliminated connectivity to the historic floodplain, stream channel complexity, functioning riparian zones, and floodplain habitats. In the Duwamish estuary, over 97 percent of the historic estuarine mudflats, marshes, and forested riparian swamps have been eliminated by channel straightening, draining, dredging, and filling. All (100˚percent) of the tidal swamps bordering the Duwamish were filled by 1940. The remaining shortened channel has been simplified and suffers from polluted sediments along with stormwater and wastewater effluent. Currently all salmonid species migrate, rear, and acclimate in this transitional area between river and marine waters. Juvenile chinook and chum salmon are most dependent on this type of habitat. Small numbers of char (bull trout/Dolly Varden char) have been consistently documented as using this reach.

There are numerous small- and medium-sized tributary streams that drain into this reach. All have seen aggressive development that in turn has made many of them inaccessible and inhospitable for salmonids. Many of these streams have high levels of impervious surfaces that have degraded and altered the historic hydrologic regime. Most of the small patches of remaining marginal habitat are disconnected and heavily impacted by stormwater-associated flows and poor water quality. Functional riparian areas have been eliminated or fragmented into a few undeveloped areas, often in the high gradient reaches where the creeks cascade down the valley walls. The potential salmonid production of these creeks is expected to continue to be limited due to current land use practices.

Habitat Limiting Factors and Impacts

Mainstem Duwamish River/Waterway:

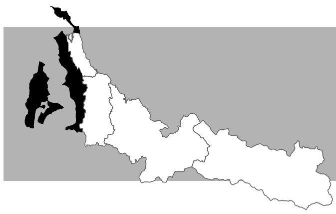
Urban and industrial land use practices that have:

- Dredged, channelized, and filled 97 percent of the estuarine mudflats, marshes, and forested riparian swamps that formerly comprised the estuary;
- Simplified the remaining channel and severely reduced riparian function; and
- Polluted the remnant, shortened channel with stormwater and wastewater effluent.

Tributaries:

Development that is:

- Creating fish passage barriers;
- Leaving small patches of disconnected marginal habitat;
- Altering hydrology and channel stability due to stormwater-associated flows; and
- Reducing water quality.



Nearshore Sub-watershed
(Independent Tributaries to Puget Sound and Vashon-Maury Islands)

Human population: 241,000

Primary designated land uses: on mainland: residential (68˚percent), industrial (10 percent); on Vashon-Maury Islands: residential (90 percent)

Recently documented salmonid species present: chinook, coho, chum, and coastal cutthroat

Additional salmonid fish species historically present: unknown

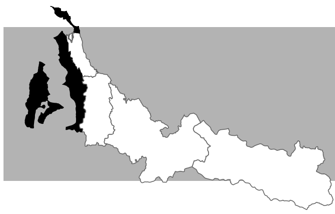
A number of independent streams in WRIA 9 drain directly into Puget Sound. Among the largest are Miller, Des Moines, and Bow Lake Creeks on the mainland. Vashon-Maury Islands also host a number of direct drainages. With the exception of a few streams, most have small drainage areas and corresponding flows.

While a few of these streams are relatively intact and support small populations of salmonids, most are heavily impacted by urbanization and no longer function well to support salmonids.

Habitat Limiting Factors and Impacts

Urban and industrial land use practices that are:

- Creating fish passage barriers;
- Reducing the amount of large woody debris and channel complexity;
- Causing chronic water quality problems; and
- Simplifying the remaining channel and severely reducing riparian functions.



Nearshore Sub-watershed
(Estuarine/Marine Waters and Habitats)

Human population: see Nearshore Sub-watershed (page 12)

Primary designated land uses: see Nearshore Sub-watershed (page 12)

Recently documented fish species present: all species of juvenile and adult salmonids

The nearshore — the boundary between saltwater and land that stretches from beach bluffs out into the shallows of Puget Sound — provides an important link in the life history of salmonids. All anadromous salmonids use the nearshore for physiological transition, feeding, refuge, and as a migration route to and from the ocean. Most salmonid species are dependent upon the nearshore for juvenile rearing. Much of the greater Puget Sound estuary shoreline has been filled, armored, and developed. Extensive areas have been dredged to maintain navigation along piers and within marinas. The supply of beach sediment has been curtailed and water quality problems stemming from upland land use practices have affected nearshore habitats. It is estimated that marine riparian vegetation exists along only 11 percent of the WRIA 9 shoreline (excluding Vashon-Maury Islands). This affects not only salmonids produced in WRIA 9 watersheds but also those produced in other Puget Sound watersheds that use WRIA 9 shorelines for support during migration.

All migratory juvenile salmonids are dependent on healthy estuarine and nearshore environments. Some species, such as chinook, chum, and pink salmon, are more dependent on a healthy estuary environment for physiological transition and rearing prior to their ocean migration. Nearshore habitats produce important food items for all life stages of salmonids. Especially important are the forage fish (e.g., sand lance, surf smelt, and herring) that require this area to spawn and rear.

Habitat Limiting Factors and Impacts

Urban and industrial land use practices that are:

- Altering or destroying significant amounts of nearshore habitat;
- Interrupting critical habitat-forming processes;
- Fragmenting or destroying marine riparian corridors; and
- Contributing toxic chemicals and harmful organic compounds to nearshore waters and sediments.

IV. RECOVERY STRATEGY FOR THE GREEN/DUWAMISH WATERSHED

A multi-species salmonid recovery strategy was developed for the Green/Duwamish watershed using the information collected for this report. The strategy relies heavily upon opening the currently untapped potential for salmonid recovery in the Upper Green River Sub-watershed. Dams have blocked access to 106 lineal miles of stream habitat and about half of the watershed acreage. The Upper Sub-watershed is large enough and the habitat forming processes are still relatively intact or in a process of recovery to allow this area to function as salmonid refugia. This refugia can seed the downstream habitat, with a potential to greatly increase natural salmonid production, especially for coho, chinook, steelhead, and cutthroat salmonids. Implementation of the strategy relies on two critical or key actions: (1) restoration of efficient upstream and downstream fish passage at the dams; and (2) ensuring that the juveniles produced in the Upper Green River Sub-watershed are provided with essential habitat functions in the downstream areas of WRIA 9. In addition, it is essential to protect intact habitats and properly functioning processes that are currently supporting existing salmonid populations throughout the WRIA.

V. NEXT STEPS

The Habitat Limiting Factors and Reconnaissance Assessment Report is the first coordinated step toward salmonid recovery in WRIA 9. It lays the groundwork for a comprehensive conservation planning effort over the next five years. This multi-species effort focuses on habitat issues affecting the decline of salmonids and other species. The planning effort will unfold in four stages over the next five years. Following the Habitat Limiting Factors and Reconnaissance Assessment Report, a Near-term Action Agenda is expected to be completed in 2001. This Agenda will guide interim and immediate actions. Also in 2001, a Strategic Assessment will begin. This will culminate in a report in mid-2003 that will help fill important data gaps. The Comprehensive Conservation Plan is the ultimate product of the WRIA 9 planning process. It will guide long-term salmonid conservation and recovery actions in the watershed. The goal is to have the Comprehensive Conservation Plan approved by the National Marine Fisheries Service and the U.S. Fish and Wildlife Service by June 2005.

Habitat Limiting Factors and Reconnaissance Assessment Report

Green/Duwamish and Central Puget Sound Watersheds

(Water Resource Inventory Area 9 and Vashon Island)

Volume I

December 2000

KING COUNTY

Washington State Conservation Commission

Habitat Limiting Factors and Reconnaissance Assessment Report
Green/Duwamish and Central Puget Sound Watersheds
(WRIA 9 and Vashon Island)

Acknowledgments

The Habitat Limiting Factors and Reconnaissance Assessment Report would not have been possible without the support and cooperation of many individuals, groups and agencies. The members of the Green/Duwamish Technical Advisory/Factors of Decline Subcommittee are gratefully thanked for their major contributions. This committee is an interjurisdictional and agency team comprised of individuals with technical backgrounds in ecology, hydrology, fisheries biology, fluvial geomorphology, water quality, and engineering. The Committee's expertise and familiarity with the habitats within the subwatersheds of Water Resource Inventory Area (WRIA) 9 and Vashon and Maury Islands and their interest and willingness to share their knowledge contributed substantially to this report.

Technical Editors:

John Kerwin, Washington Conservation Commission (Washington CC)
Tom S. Nelson, King County Department of Natural Resources (King County DNR)

Report Coordinator:

Jennifer Rice, King County DNR

Principal Authors of Individual Chapters and Reports:

Executive Summary .... Dennis Clark, King County DNR
Introduction .... Jennifer Rice, King County DNR
Salmon Habitat Needs .... John Kerwin and Dr. Carol Smith, Washington CC
Salmon Stock Status .... John Kerwin, Washington CC
Genetics .... John Kerwin, Washington CC

Factors of Decline/Conditions
Land Use .... Perry Falcone and Doug Osterman, King County DNR
Judith Noble, City of Seattle
Water Quality .... Lorin Reinelt, King County DNR
Hydrology .... Sue Madsen, R2 Resource Consulting (R2)
Hydrology Addendum
(Naturalized Flow Regime) .... Clint Loper, King County DNR
Sediment/Streambed .... Sue Madsen, R2
Hydromodification .... Sue Madsen, R2
Riparian .... Sue Madsen, R2
Fish Passage .... Sue Madsen, R2
Non-Native Species .... Sue Madsen, R2

Tributaries.. John Kerwin, Washington CC

The assistance of Kurt Beardlsee and Jamie Glasgow, both of Washington Trout, was invaluable in the development of the Vashon and Maury Islands components of the tributary reports.

Estuary and Nearshore Conditions.............. Laura Blackmore, King County DNR

Brian Murray, Doug Henderson and Daniel Smith of King County DNR, are thanked for their efforts in gathering data, and Ken Rauscher for his assistance in data analysis.

Dr. Jon Houghton and Jim Starkes, both of Pentec Environmental, provided information about the Duwamish River estuary.

Gregory Williams, Battelle Marine Sciences Laboratory, Jim Starkes, Pentec Environmental are the principal authors of the draft State of the Nearshore Report from which much of the Estuary and Nearshore Conditions chapter is drawn. Jim Brennan, King County DNR, provided review and comment. The Nearshore Technical Committee provided review of initial drafts of this chapter.

Assessment.. Tom Nelson, King County DNR
John Kerwin, Washington CC

Substantial assistance and review of this chapter were provided by members of the WRIA 9 Planning Work Group.

Conclusions .... Tom Nelson, King County DNR
John Kerwin, Washington CC

Substantial assistance and review of this chapter were provided by members of the WRIA 9 Planning Work Group.

Fish Distribution Maps

The Fish Distribution Maps were initially developed through a workshop held in May 1999. Individuals from numerous governmental agencies, Indian tribes and non-profit organizations, and private citizens knowledgeable about salmonid utilization in the watershed participated. Information from databases, including StreamNet, SSHIAP and the WDFW Spawning Ground Survey Database were also utilized. The initial work product was further reviewed and refined during a workshop in 2000.

Perry Falcone, King County DNR, coordinated map production.

Fish Barrier Map

The Fish Barrier Maps shown in this report were initially developed by using information from field notes and databases including StreamNet, SSHIAP and the Washington Department of Transportation fish barrier database. The initial work product was further reviewed and refined by the WRIA 9 Technical Committee at a workshop in 2000.

Reviewers and Participants:

This report would not have been possible without the support, contributions, and cooperation of many reviewers and participants, including:

Washington Environmental Council, Doreen Johnson; *Federation of Fly Fishermen*, Howard Johnson; *EcoCline Consulting & Muckleshoot Indian Tribe*, Rod Malcom; *Martha Bean Consulting*, Martha Bean; *Northwest Indian Fisheries Commission*, Jennifer Cutler and Devin Smith; *Pentec Environmental*, Jon Houghton; *PIE Engineering*, Glenn Grette; *People for Puget Sound*, Jacques White; *Puget Sound Water Quality Action Team (PSWQAT)*, Kathy Minsch and Kathy Taylor; *R2 Resource Consulting*, Sue Madsen; *Shannon and Wilson, Inc.*, Richard Brocksmith; *Trout Unlimited*, Hal Boynton and Joe Stone; *Tacoma Public Utilities*, Paul Hickey; *US Army Corps of Engineers*, Patrick Cagney, Fred Goetz, and Captain Glen Reed; *US Forest Service*; Karen Bergeron; *Washington CC*, John Kerwin and Ed Manary; *Washington Department of Ecology (WDOE)*, Lori LeVander and Kevin Fitzpatrick; *Washington Department of Fish & Wildlife*, Mike Chamblin and Kirk Lakey; *Washington Department of Natural Resources*, Walt Pulliam; *City of Auburn*, Dennis Dowdy, Tim Carlaw and Paul Krauss; *City of Kent*, Bill Wolinski; *City of Normandy Park,* Steve Bennett; *City of Renton,* Ron Straka and Allen Quynn; *City of Seattle*, Joan Kersnar, Judith Noble and Jennie Goldberg; *City of Tukwila*, Ryan Larsen, Ryan Partee, Gary Schulz and Phil Fraser; *Port of Seattle*, George Blomberg; *King County Department of Development and Environmental Services (DDES)*, Don Finney; *King County DNR*, Laura Blackmore, Jim Brennan, Jeff Burkey, Dennis Clark, Betsy Cooper, Hilary Culverwell, Perry Falcone, Linda Hanson, Philip Hartigan, David Hartley, Judy Herring, Jacoba Johnson, Josh Kahan, Andy Levesque, Clint Loper, Eric K. Nelson, Tom Nelson, Sarah Ogier, Doug Osterman, Colleen Rasmussen, Jackie Reid, Lorin Reinelt, Jennifer Rice, Ruth Schaefer, David St. John, Katy Vanderpool, David Masters, Randy Shuman and Bob Fuerstenberg.

Other Contributors:

WRIA 9 Planning Work Group
WRIA 9 Public Outreach Work Group

Program Managers:

Ed Manary, Washington CC
Doug Osterman, King County DNR

General Editing and Word Processing:

Sally A. Thomas
Marcia McNulty

Report Design, GIS and Graphics:

Laurel Preston, King County DNR
Collene Gaolach, King County DNR
Sandy Kraus, King County DNR
Ron McFarlane, NWIFC

WRIA 9 Steering Committee:

King County Metropolitan Council, Dwight Pelz, Chair, Councilmember; *City of Seattle*, Margaret Pageler, Councilmember, Jan Drago, Councilmember; *City of Auburn, Green/Duwamish Watershed Forum*, Charles Booth, Mayor*; City of Kent, Green/Duwamish Watershed Forum* Tim Clark, Councilmember; *City of Renton, Green/Duwamish Watershed Forum*, Jay Covington, Chief Administrative Officer; *City of Burien, Central Puget Sound Watershed Forum*, Stephen Lamphear, Councilmember; ; *City of Tukwila, Green/Duwamish Watershed Forum*, Steve Mullet, Mayor; *Green/Duwamish Watershed Alliance*, John Beal and James Rasmussen*; US Army Corps of Engineers*, Noel Gilbrough; *Washington Department of Fish and Wildlife (WDFW),* Kirk Lakey, and Phil Schneider; *City of Normandy Park, Central Puget Sound Watershed Forum*, John Wiltse, Councilmember; *Port of Seattle,* Thomas A. Newlon and Denise Stiffarm; *Washington Department of Natural Resources (WDNR),* Art Tasker; *Washington Department of Ecology (DOE),* Janet Thompson*; Washington Environmental Council*, Doreen Johnson; *King County Agricultural Commission*, Burr Mosby; *King Conservation District*, Max Prinsen; *Covington Water District*, Judith Nelson and Lys Hornsby; *Tacoma Public Utilities*, John Kirner and Paul Hickey; *Trout Unlimited*, Al Barrie; *Plum Creek Timber Company*, Jeff Light and Don Nettleton; *Master Builders Association*, Peter Orser and Dick Lowell; *South County Chambers Coalition*, John Raeder; *The Boeing Company*, David Sizemore; *Washington Trout*, Marilyn Tuohy.

Recommended Citation:

Kerwin, John and Nelson, Tom S. (Eds.). December 2000. "Habitat Limiting Factors and Reconnaissance Assessment Report, Green/Duwamish and Central Puget Sound Watersheds (WRIA 9 and Vashon Island)." Washington Conservation Commission and the King County Department of Natural Resources.

Financial Contributions:

Lead Entity Salmon Restoration Grant (WRIA 9). Washington Department of Fish and Wildlife
Federal Salmon Recovery Funding Grant (FY 99). Washington State Governor's Salmon Recovery Office
Puget Sound Action Team Interagency Agreement (IAC 2000 08)
Port of Seattle
King Conservation District

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

PART I: INTRODUCTION

1. PROJECT OVERVIEW .... PART I: 1-1

2. SALMON HABITAT NEEDS .... PART I: 2-1

3. CURRENT AND HISTORIC SALMONID POPULATION .... PART I: 3-1

4. SALMON GENETICS .... PART I: 4-1

PART II: FACTORS OF DECLINE/CONDITIONS

1. WATERSHED-WIDE CONDITIONS

1.1. LAND USE .... PART II: 1.1-1
1.2. WATER QUALITY .... PART II: 1.2-1

2. MAINSTEM GREEN/DUWAMISH RIVER CONDITIONS .... PART II: 2-1

2.1. HYDROLOGY .... PART II: 2.1-1
2.2 SEDIMENT TRANSPORT .... PART II: 2.2-1
2.3 HYDROMODIFICATION .... PART II: 2.3-1
2.4 RIPARIAN CONDITION .... PART II: 2.4-1
2.5 FISH PASSAGE .... PART II: 2.5-1
2.6 NON-NATIVE SPECIES .... PART II: 2.6-1

3. TRIBUTARY CONDITIONS .... PART II: 3.1

3.1 LONGFELLOW CREEK SUBBASIN .... PART II: 3.1-1
3.2 HAMM CREEK SUBBASIN .... PART II: 3.2-1
3.3 SPRINGBROOK CREEK SUBBASIN .... PART II: 3.3-1
3.4 MILL CREEK & MULLEN SLOUGH SUBBASIN .... PART II: 3.4-1
3.5 EAST HILL TRIBUTARIES OF THE LOWER GREEN RIVER .... PART II: 3.5-1
3.6 MIDDLE GREEN RIVER TRIBUTARIES .... PART II: 3.6-1
3.7 SOOS CREEK SUBBASIN .... PART II: 3.7-1
3.8 NEWAUKUM CREEK SUBBASIN .... PART II: 3.8-1
3.9 COAL AND DEEP CREEKS SUBBASINS .... PART II: 3.9-1
3.10 UPPER GREEN RIVER AND SUNDAY CREEK WATERSHED ADMINISTRATIVE UNIT .... PART II: 3.10-1
3:11 LESTER WATERSHED ADMINISTRATIVE UNIT .... PART II: 3.11-1
3.12 INDEPENDENT NEARSHORE TRIBUTARIES IN WRIA 9 .... PART II: 3.12-1
3.13 VASHON AND MAURY ISLANDS SUBBASIN .... PART II: 3.13-1

4. SUMMARY OF ESTUARY AND NEARSHORE CONDITIONS .... PART II: 4-1

PART III: SUMMARY

1. ASSESSMENT .... PART III: 1-1

2. CONCLUSIONS

2.1 PRINCIPLES TO GUIDE SALMONID RECOVERY .... PART III: 2.1-1

2..2 STRATEGY: UNLOCK THE NATURAL POTENTIAL ....PART III: 2.2-1

2..3. SPECIFIC ACTION RECOMMENDATIONS ....PART III: 2.3-1

PART IV: GLOSSARY AND BIBLIOGRAPHY

1. ACRONYMS AND GLOSSARY

2. BIBLIOGRAPHY

PART V: APPENDIX (In separate appendix file)

FISH DISTRIBUTION MAPS

EVOLUTIONARILY SIGNIFICANT UNIT MAPS

HISTORICAL AND CURRENT SALMONID POPULATIONS,
LIFE HISTORIES AND HABITAT CONDITIONS--DRAFT REPORT

LAND USE APPENDIX

HABITAT MATRIX

PART I
INTRODUCTION

1. Project Overview

2. Salmon Habitat Needs

3. Current and Historic Salmonid Population

4. Salmon Genetics

PART I: INTRODUCTION

1. Project Overview

1. PROJECT OVERVIEW

BACKGROUND

In March 1999, the National Marine Fisheries Service (NMFS) listed Puget Sound chinook salmon (*Oncorhynchus tshawytscha*) as a threatened species under the Endangered Species Act (ESA). In November 1999, the U.S. Fish and Wildlife Service listed Bull Trout as a threatened species under the ESA. In addition to the recent listing of these two species, it is anticipated that in the next several years additional salmonid and other fresh- and saltwater species native to the Puget Sound Region will be listed.

All in all, at least 106 wild salmon stocks in the Pacific Northwest have been extirpated, 214 are at high or moderate risk of extinction, and many have been listed or are being reviewed for listing under the Endangered Species Act. A number of natural and anthropogenic factors have contributed to these declines:

- Hydropower operations;
- Over exploitation;
- Artificial propagation;
- Climatic and oceanic changes, and destruction; and
- Degradation of habitat through land use and water-use practices.

Although the relative impact of these different factors varies among basins and river systems, habitat loss and degradation are considered contributing factors in the decline of most salmonid populations (Spence et al.1996).

Partly in anticipation of the recent and impending listing of multiple aquatic species in the Northwest, the state of Washington has passed several state laws directing planning efforts to address issues of habitat degradation in fresh and salt water. In 1998-99, the state of Washington passed three laws (house bills 2514 and 2496, and senate bill 5595)to direct state watershed planning. These bills outline geographic areas, organizational structures, and funding mechanisms to develop and implement watershed plans throughout the state. Bill 2514 is primarily focused on in-stream flow issues, while house bill 2496 and senate bill 5595 are primarily focused on addressing Habitat Limiting factors of decline. The geographic areas identified for both of these planning efforts are called Water Resource Inventory Areas (WRIAs), which were originally designed as stream inventory areas. The state of Washington is divided into 62 WRIAs.

Under house bill 2496 (and reasserted by senate bill 5595), the State Conservation Commission was tasked with developing a Limiting Factors Report for each of the WRIAs in the state of Washington. In addition, these bills called for lead entities in each of the WRIAs to establish a Steering Committee and Technical Committee to identify funding priorities for salmon conservation, and to develop a strategy or plan for addressing Habitat Limiting factors to salmonid recovery in their respective WRIA.

In WRIA 9, (the geographic area including the Green/Duwamish River watershed and the independent drainages to Puget Sound from Elliott Bay south to the Puyallup watershed), the WRIA 9 Steering Committee and the Washington Conservation Commission have teamed up to develop a Habitat Limiting Factors and Reconnaissance Report to begin to lay the groundwork for the future development and implementation of a conservation plan for the WRIA.

The geographic scope of the WRIA 9 Habitat Limiting Factors and Reconnaissance Report includes WRIA 9 drainages and nearshore areas, and Vashon Island (although it is located in WRIA 15, Vashon Island falls within the jurisdictional boundaries of King County). This report covers both fresh- and saltwater habitats for salmonids in the geographic boundaries. The report:

- Brings together existing information on past and present conditions of salmonids and salmonid habitat in the watershed;

- Identifies important problems and habitat limiting factors contributing to salmonid decline; and

- Highlights gaps in current data and technical understanding.

Along with other Habitat Limiting Factors reports being developed across the state, the information in this report will help to create a consistent approach for identifying habitat functions that require protection and restoration to maintain and increase naturally spawning and self-sustaining populations of salmonids. Closer to home, the document will be used as a critical building block for continued assessment and planning efforts in WRIA 9.

The WRIA 9 Steering Committee is responsible for developing a Conservation Plan for the WRIA 9 geographic area by 2005. This Committee was established in 1998 and consists of representatives from local and state governments, the environmental community, and businesses in the WRIA. It is supported by a Factors of Decline Subcommittee (FODS) and Nearshore Technical Committee (NTC), both of which are responsible for developing the scientific basis for the planning effort. The Steering Committee is also supported by a Planning Work Group responsible for helping to move the technical information into policy; and a Public Outreach Workgroup responsible for developing and implementing a public outreach strategy for the planning effort.

The WRIA 9 planning effort also supports the Tri-County Model Conservation Planning Effort. The Tri-County initiative brings together local governments, environmental groups, and businesses in Snohomish, King, and Pierce Counties to address the habitat-related factors of salmonid decline. King County is the Lead Entity for the WRIA 9 Salmon Conservation Planning Effort and provides staff support to the Steering Committee and supporting committees. Several State and Federal grants and programs have helped fund this planning effort. In addition, other local jurisdictions within the WRIA boundary provide staffing (and beginning in 2001, significant funding) to this effort.

WRIA 9 PLANNING PRODUCTS

The WRIA 9 salmonid conservation planning effort is a multi-species effort, focused on habitat issues affecting the decline of salmonids and other species The effort is expected to take five years and is broken up into four stages:

- Habitat Limiting Factors and Reconnaissance Report;
- Strategic Assessment;
- Near-term Action Agenda; and
- A WRIA 9 Comprehensive Conservation Plan. (taken from the WRIA 9 Steering Committee Approved Work Program, July 2000).

HABITAT LIMITING FACTORS RECONNAISSANCE REPORT

The Habitat Limiting Factors and Reconnaissance Report brings together existing information on conditions of salmonids and salmonid habitat in the WRIA. It is based largely on a collection of readily available information in the literature and institutional knowledge. It identifies important problems and clear factors contributing to salmonid decline, and highlights current gaps in data and technical understanding. This document will serve as a critical building block for the Strategic Assessment, and will provide the scientific foundation for the development of a Near-term Salmon Action Agenda.

STRATEGIC ASSESSMENT

The Strategic Assessment will build on information in the Habitat Limiting Factors and Reconnaissance Report. It will involve original research and collection and analysis of data to fill important information gaps identified by the Habitat Limiting Factors and Reconnaissance Report. This will result in a richer, more comprehensive understanding of problems and opportunities in the watershed related to salmonid conservation and recovery. The Strategic Assessment will be initiated in 2001 and will culminate in a report to the WRIA 9 Steering Committee in approximately June 2003. This work will provide the scientific foundation for the development of a Comprehensive Conservation Plan for WRIA 9.

NEAR-TERM ACTION AGENDA

This document will recommend early and interim action projects, policies, and programs, based on the results of the Habitat Limiting Factors and Reconnaissance Report. It will include recommended actions related to habitat protection and restoration, and policy and program responses to other high-priority habitat limiting factors in the watershed. This agenda will guide decisionmaking and action by local governments and other implementers in WRIA 9 while the final conservation plan is being completed. The goal is for the Steering Committee to adopt a Near-term Action Agenda by the end of 2001. This Agenda will then serve as an important building block for development of the Comprehensive Conservation Plan.

COMPREHENSIVE CONSERVATION PLAN

The Comprehensive Conservation Plan is the ultimate product of the WRIA 9 planning process. It will guide long-term salmonid conservation and recovery actions in the watershed. The WRIA 9 Steering Committee will guide development of the Plan. The goal is to have the Plan approved by the National Marine Fisheries Service and the US Fish and Wildlife Service by June 2005.

HABITAT LIMITING FACTORS AND RECONNAISSANCE REPORT SCOPE

PURPOSE

As noted above, the Habitat Limiting Factors and Reconnaissance Report is intended to serve as the Conservation Commission's Habitat Limiting factors report for WRIA 9 and as the initial phase in the WRIA 9 salmonid habitat conservation planning effort. The report is specifically intended to:

- Provide a summary of what is known about current and past salmonid species and habitat conditions in the WRIA for future reference;
- Provide baseline information for the WRIA (based on known information) for use in the implementation of an adaptive management program.
- Identify habitat factors of decline in the WRIA and associated data gaps and key findings; and
- Provide preliminary guidance for policy makers to determine next steps in the recovery process.

CONTENTS

The Habitat Limiting Factors and Reconnaissance Report is divided into an Executive Summary and the following chapters:

- **Part I: Introduction.** Includes a background and overview of the planning effort, a brief description of the watershed, a discussion of salmonid habitat needs, a Green/Duwamish salmonid stock status report, and a genetics report.
- **Part II: Factors of Decline/Conditions.** Includes habitat factors of decline for the Mainstem Green/Duwamish River, tributaries to the Green/Duwamish River, independent tributaries that flow directly to Puget Sound in WRIA 9, and stream systems on Vashon Maury Island. Nearshore conditions and factors of decline are also included in this chapter.
- **Part III: Summary.** Includes an assessment, consisting of key findings and data gaps for each factor of decline discussed in part two, and conclusions which include watershed principles, a watershed strategy, and some specific action recommendations.

- **Part IV: Glossary and Bibliography.** Contains a glossary of key terms and acronyms as well as a bibliography for the report.

- **Part V: Appendix.** The appendix includes many graphics that support the report including fish distribution maps. Several supporting documents for the Habitat Limiting Factors and Reconnaissance Report are also included in the appendix.

METHODOLOGY

The Habitat Limiting Factors and Reconnaissance Report was developed by the WRIA 9 Factors of Decline Subcommittee (FODS), with support on nearshore and estuarine issues provided by the Nearshore Technical Committee. Both committees are made up of technical staff from local, state, and federal agencies. The Nearshore Technical Committee also includes representatives from non-profit agencies, the University of Washington, the tribes, and the private sector. The effort was broken into two phases:

- Phase 1 consists of presenting existing information on each habitat factor of decline in the WRIA and identifying key findings and data gaps for each of the limiting factors.

- Phase 2 of the effort, provides an assessment of report findings and offers preliminary recommendations.

RESEARCH OF HABITAT FACTORS OF DECLINE

To facilitate a habitat factors of decline analysis, FODS subdivided the WRIA 9 drainages into four areas:

- The mainstem Green/Duwamish River and larger tributaries;

- Other select tributaries of the Green/Duwamish River;

- Independent tributaries to the Puget Sound including those on Vashon Island; and

- The nearshore and estuary environments.

The Mainstem Green River was further subdivided into four sub-watersheds:

- The Upper Green River sub-watershed [upstream of the Howard Hanson Dam at river mile (RM) 64.5)];

- The Middle Green sub-watershed (RM 32-RM 64.5);

- The Lower Green River sub-watershed (RM 11 to RM 32); and

- The Duwamish River(downstream of RM 11).

FODS began by researching each identified habitat factor of decline in the Mainstem Green/Duwamish and major tributaries and identifying key findings and data gaps for each. They then moved to an analysis of smaller tributaries to the Green/Duwamish and those draining directly to Puget Sound. Habitat factors of decline were noted for each tributary and key findings and data gaps identified. The Nearshore Technical Committee took the lead in developing a summary of factors of decline, key findings, and data gaps for the nearshore and estuary environments.

ASSESSMENT OF DATA AND NEXT STEPS

Once existing information on factors of decline was assembled and key findings were agreed upon, FODS developed an assessment matrix for each of the sub-basins studied. The purpose of the matrix is to display habitat information for each stream/river reach in a tabular format to provide a quick summary of the factors of decline for salmonids, and to show trends in habitat quality throughout the system. In addition, FODS developed a broad, long-term strategy to move the watershed toward recovery. FODS then walked through each factor of decline and made several recommendations for each. Because this is an overarching document for the watershed and does not prioritize recommendations, FODS will also develop an annual “direction document” which will be intended to provide direction for the given year for both the Strategic Assessment and the Near-Term Action Agenda.

WRIA 9 BASIN CHARACTERIZATION

WATER RESOURCE INVENTORY AREA 9 OVERVIEW

The climate in the Green River watershed is generally mild, with wet winters and dry, cool summers. Annual precipitation varies widely, ranging from over 100 inches in the Cascade foothills and decreasing westward to 35 inches in Seattle. The human population in WRIA 9, estimated to be 564,000 in the 2000 census, is mostly concentrated within the lower (west) end of the watershed, but the fastest rate of population increase is in the suburban cities and nearby unincorporated areas east of Seattle (King County 2000).

The Green/Duwamish River is a sixth-order, 93-mile-long river system that originates in the Cascade Mountains about 30 miles northeast of Mount Rainier and flows into Puget Sound at Elliott Bay in Seattle. The Green River basin comprises 566 square miles and is bounded on the north by the Cedar-Sammamish watershed (WRIA 8) and to the south by the Puyallup watershed (WRIA 10). The mean annual flow in the lower Green River (measured at the Auburn gage) is currently 1,350 cfs, the average historic minimum flow prior to construction of Howard Hanson Dam was approximately 140 cfs, and the maximum historic recorded flow is 28,000 to 30,000 cfs. Since construction of Howard Hanson Dam, the average minimum flow is 210 cfs, and the maximum recorded flow was approximately 11,500 cfs. Part of the large discrepancy between current and historical maximum flows is the fact that the watershed and flows have been reduced by 70 percent due to diversions of the White, Black, and Cedar Rivers. (Schaefer et. al. 2000)

The nearshore environment encompasses the shorelines of Puget Sound that fall within WRIA 9, as well as Vashon and Maury Islands. The northern boundary of the WRIA 9 nearshore is West Point, and the southern boundary is just north of Dumas Bay in the City of Federal Way. Its seaward boundary is the outer limit of the photic zone [approximately -20m below Mean Lower Low Water(MLLW)], or the depth beyond which there is insufficient sunlight penetration for active photosynthesis. The nearshore environment extends landward to include coastal landforms such as bluffs, the backshore, sand spits and coastal wetlands, as well as marine riparian vegetation on or adjacent to any of these areas. In addition, the nearshore environment includes sub-estuaries such as the tidally influenced portions of river and stream mouths.

WRIA 9 PHYSIOGRAPHY

The Green/Duwamish basin can be divided into six physiogeographic parts:

- The Upper Green Sub-watershed [headwaters to the Howard Hanson Dam at RM 64.5];
- The Middle Green River (Howard Hanson Dam to the Soos Creek Confluence at RM 32);
- The Lower Green sub-watershed (Soos Creek confluence to the Black River confluence at RM 11);
- The Duwamish River sub-watershed (downstream of RM 11);
- Independent Tributaries to Puget Sound (including tributaries on Vashon Island); and
- The Nearshore sub-watershed.

Upper Green River Sub-watershed

From the vicinity of Blowout Mountain and Snowshoe Butte, the river flows generally west and northwest for approximately 25 miles through narrow-valleyed, steeply sloped, densely forested terrain, gathering flows from Sunday, Sawmill, Champion, Smay and Charlie Creeks, as well as from the North Fork Green River. (Schaefer et. al. 2000). This sub-watershed contains about 45% of the Green/Duwamish watershed area and stream mileage. Logging has occurred in this area, and the upland vegetation is a checkerboard of old-growth, second-growth, and recently logged areas. Tacoma Public Utilities (TPU) operates a well field in the North Fork Green River drainage above Howard Hanson Dam. Immediately below the North Fork Green River confluence at approximately RM 64.5 is Howard Hanson Dam, which the U.S. Army Corps of Engineers constructed in 1961 as a flood control facility. The reservoir behind the dam currently provides up to 106,000 acre-feet of storage at elevation 1,206 feet.

Middle Green River Sub-watershed

At approximately RM 61.0, TPU maintains municipal water supply diversion facilities which have blocked anadromous fish migration since construction of this facility in 1913. Below TPU's diversion, the Green River flows between narrow, steeply sloped valley walls through mostly forested mountain terrain before emerging from the mouth of the Green River Gorge at approximately RM 46.4 at the upstream end of Flaming Geyser State Park. At this point, the river flows through a broad, gently sloped valley with mostly agricultural land uses. In contrast with upstream areas, extensive portions of this reach are affected by levees and revetments that constrain channel migration while not necessarily containing floodwaters. Several large state and county parks abut the river in this segment, providing largely forested land.

Lower Green River Sub-watershed

Downstream from the Soos Creek confluence, the Green River enters increasingly urbanized areas within the Cities of Auburn, Kent and Tukwila. Except for occasional stretches of park land, this stretch of the river is bordered by an increasingly densely developed mixture of residential, commercial and industrial land uses. The entire Green River mainstem throughout this reach is degraded with poor habitat quality. The construction of a nearly continuous system of revetments and levees within this area has eliminated functional riparian habitats along many miles of the river channel and has disconnected most remnant side channels and tributaries from the active floodplain.

Green/Duwamish Estuary

Downstream from the Black River confluence (RM 11) (which is also considered the upstream limit of tidal influence), the Green River continues as the Duwamish River, which flows past scores of industrial and commercial facilities as well as scattered urban parks and single and multi-family residences. The Duwamish River and Elliott Bay have been extensively modified over the last 100 years, including the filling of 97 percent of their original wetlands and shallow sub-tidal habitats. These habitats have also been adversely affected by extensive river channelization and dredging (Schaefer et. al. 2000). Substantial sediment contamination and water quality problems have also been documented in the Duwamish River and Elliott Bay.

Independent Tributaries

The nearshore tributaries of WRIA 9 include 15 independent streams that directly enter Puget Sound. Bordered by Fauntleroy Creek to the north and Little Joe’s Creek to the south, these streams are all typical of Puget Sound lowland drainages that receive their flow from springs, lake outlets, rainfall and groundwater runoff. Miller and Des Moines Creeks are the largest and generally have the largest amount of information. All of the Nearshore creeks in WRIA 9 have experienced the types of habitat degradation associated with industrial development and/or urbanization.

Nearshore

The WRIA 9 nearshore includes dozens of habitat types that support hundreds of species. However, residential, commercial, and industrial development has altered the WRIA 9 nearshore environment significantly by interrupting habitat-forming processes, destroying or altering habitat, and degrading water and sediment quality. Healthy marine riparian vegetation has disappeared from much of the mainland shoreline, and acres of marshes and tidal flats have been filled or dredged. On the mainland shoreline, few natural areas remain, even in parks. A greater number of undeveloped areas persist on Vashon and Maury Islands. Significant data gaps remain in scientists’ understanding of this complex and rich environment.

HISTORICAL OVERVIEW

Historically, the White, Green, Black and Cedar rivers flowed into the Duwamish River, and the system drained an area of over 1,600 square miles. In the early 1900s, the White, Black and

Cedar rivers were diverted, reducing the Green/Duwamish drainage area to 556 square miles (Schaefer et. al. 2000)

Development in the watershed began in the mid-1800s with the building of settlements and homesteads near the present-day towns of Tukwila and Kent. In the 1870s through the 1890s major rail lines were constructed in the Green River valley. The Green/Duwamish basin was one of the first areas west of the Cascades to be logged, and the majority of logging in the lowlands occurred between 1870 and 1910.

Major flooding occurred on the White and Green Rivers in 1906. Shortly thereafter, the White River was diverted into the Stuck River, which flowed into the Puyallup River. This diversion was completed in 1911. Diversion of the White River reduced flows at the mouth of the Duwamish from an estimated 2,500-9,000 cubic feet per second (cfs) to a mean annual flow of 1,700 cfs (Fuerstenberg et al., 1999).

In 1916, completion of the Lake Washington Ship Canal diverted the Cedar River from the Green/Duwamish Watershed into Lake Washington, and eliminated the Black River. The diversion of the White, Black and Cedar Rivers reduced the size of the Green River watershed to just over 30 percent of its original area.

Development in the Duwamish River Estuary accelerated in the late 1800s. Excavation of the Duwamish Waterway through the estuary was begun in 1895 and was completed in 1917. Construction of this waterway converted approximately 17.5 linear miles of meandering, distributed channel into 10 miles of deep, uniform channel with a substantial hardened shoreline (Schaefer et. al. 2000). Material excavated during construction of the waterway was used to fill adjacent intertidal shallows and wetlands. Based on historic maps, the pre-development estuary included approximately 1,230 acres of tidal freshwater marshes, 1,270 acres of tidal marsh-land, and 1,450 acres of intertidal mudflats and shallows. By 1940, essentially all of the estuary’s shallows, flats, marshes, and swamps were converted to filled, flat land suitable for industrial development.

Tacoma completed construction of the Headworks Dam for water supply near the town of Palmer in1913, completely blocking fish migration to the upper river and tributaries. In 1962, the Howard Hanson Dam was completed by the Corps of Engineers to the east of Eagle Gorge of the upper Green River. The main purpose of the dam is flood control, with water supply and fisheries conservation as additional authorized purposes, although no fish passage facilities are incorporated into this dam. (Schaefer et. al. 2000)

Despite the many alterations in the watershed and estuary, the Green/Duwamish system continues to support important fisheries and represents a valuable resource to be protected and restored.

PART I: INTRODUCTION

2. Salmon Habitat Needs

2. SALMON HABITAT NEEDS

Since the recession of the last ice age 10,000 years ago, Washington State anadromous salmonid populations have evolved in their specific habitats (Miller, 1965). Water chemistry, flow, and the physical and biological components unique to their natal streams, estuaries and ocean environment have helped shape the genotypic and phenotypic characteristics of each salmon population. These unique attributes have resulted in a wide variety of distinct salmon stocks for each salmon species throughout the state. Within a given species, stocks are relatively distinct population units that do not extensively interbreed with each other. Stocks do not extensively interbreed with each other because returning adults rely on a stream's unique chemical and physical characteristics to guide them to their natal spawning grounds. This maintains the separation of stocks during reproduction, thus preserving the distinctiveness of each stock.

Throughout the salmon's life cycle, the dependence between the environment and a stock continues. For example, adults spawn in areas near their origin because reproductive survival favors natural selection for those that exhibit this behavior. The timing of juveniles leaving the river and entering the estuary is tied to high natural river flows. It has been theorized that rapid out-migration reduces predation on the young salmon and perhaps coincides with favorable feeding conditions in the estuary (Wetherall, 1971). These are a few examples that illustrate how a salmon stock and its environment are intertwined throughout the entire life cycle.

Salmon habitat includes the physical, chemical and biological components of the environment that support salmon. Within freshwater and estuarine environments, these components include:

- Water quality;
- Water quantity or flows;
- Stream and river physical features (e.g., sediment, substrate, and woody debris);
- Riparian zones;
- Upland terrestrial conditions; and
- Ecosystem interactions as they pertain to habitat.

These components are closely intertwined. Low stream flows can alter water quality by increasing temperatures and decreasing the amount of available dissolved oxygen, while concentrating toxic materials. Heavy sediment loads can also impact water quality by increasing in channel instability and decreasing spawning success. The riparian zone interacts with the stream environment, providing nutrients and a food web base, woody debris for habitat and flow control (stream features), filtering runoff prior to surface water entry (water quality), and providing shade to aid in water temperature control. Riparian zones serve similar functions in the estuarine and nearshore environment.

Optimal freshwater habitat for salmonids includes clean, cool, well-oxygenated water flowing at a normal (natural) rate for each stage of freshwater life. Salmonid survival depends upon specific habitat requirements for egg incubation, juvenile rearing, migration of juveniles to saltwater, estuary rearing, ocean rearing, adult migration to spawning areas, and spawning. These requirements can vary by species and even by individual stock.

When adults return to spawn, they not only need adequate flows and water quality, but also unimpeded passage to their natal grounds. They need deep pools with vegetative cover and instream structures such as root wads for resting and shelter from predators. Successful spawning and incubation requires sufficient gravel of the right size for that particular population, in addition to the constant need of adequate flows and water quality, all in unison at the necessary location.

After spawning, the eggs need stable gravel that is not choked with fine-grained sediment. River channel stability is vital at this life history stage. Floods have their greatest impact to salmon populations during incubation where they can scour redds. Flood impacts may be exacerbated by human activities that lead to increased sediment loads, point and non-point source pollutants, and the removal of instream LWD. Floods also produce and maintain habitats. They provide the necessary energy to scour deep pools and create side channels. In a natural river system, the upland areas are forested. Trees and their roots store precipitation, which slows the rate of storm water into the stream. A natural, healthy river is sinuous and contains large pieces of downed wood contributed by an intact, mature riparian zone. Both slow the speed of water downstream. Natural river systems have floodplains that are connected directly to the river at many points, allowing the floodplains to store flood water and later discharge this storage back to the river during lower flows. In a healthy river, erosion or sediment input is great enough to provide new sediments (i.e.: gravel) for spawning and incubation, but does not overwhelm the system, raising the riverbed and increasing channel instability. A stable incubation environment is essential for salmon, requiring a complex interaction of nearly all the habitat components contained within a natural river ecosystem.

After the young salmonid fry emerge from the gravel nests (redds), certain species (such as chum, pink, and some chinook salmon) quickly migrate downstream to the estuary. Other species, such as coho, steelhead, bull trout, cutthroat, sockeye and chinook, will search for suitable rearing habitat within the side sloughs and channels, tributaries, and spring-fed “seep” areas, as well as the outer edges of the stream. These quiet-water side margins and off channel slough areas are vital for early juvenile rearing habitats. The presence of woody debris and overhead cover aid in food and nutrient inputs, provide localized areas of reduced water velocities for energy conservation as well as provide protection from predators. For most of these species, juveniles use this type of habitat in the spring. Most sockeye populations migrate from their gravel nests quickly to larger lake environments where they have unique habitat requirements. The adult sockeye observed spawning in the Green River may be strays from other systems or represent a riverine life history stock.

As growth continues, the juvenile salmon (parr) move away from the quiet shallow areas to deeper, faster areas of the stream. The species that exhibit this behavior include coho, steelhead, bulltrout, and certain chinook. For some of these species, this movement is coincident with the summer low flows. Low flows typically constrain salmon production for stocks that rear during summer within the stream. In non-glacial streams, precipitation, melting snow packs, connectivity to wetland discharges, and groundwater maintain summer flows inputs. Reductions in these inputs will reduce that amount of habitat; hence the number of salmon which are dependent on adequate summer flows are reduced.

In the fall, juvenile salmon that remain in freshwater begin to move out of the mainstems, and again, off-channel habitat becomes important. During the winter, coho, steelhead, bull trout, cutthroat and any remaining chinook parr require off-channel habitats to sustain their growth and protect them from predators and high winter flows. Wetlands, off-channel/side channel stream habitat protected from the effects of high flows, and pools with overhead cover are important habitat components during this time.

Except for resident bull trout, cutthroat and steelhead (rainbow), juvenile parrs convert to smolts as they migrate downstream towards the estuary. Again, flows are critical, and food and shelter are necessary. The natural flow regime in each river is unique, and has shaped the stock's characteristics through adaptation over the last 10,000 years. Because of the close inter-relationship between a salmon stock and its stream, survival of the stock depends heavily on natural flow patterns.

Estuaries and nearshore areas support a critical life stage that can be a determinant to successful juvenile survival and the subsequent adult returns. The estuary provides essential habitat for physiological transition, refuge, foraging and rapid growth. Some salmon species are more heavily dependent on estuaries, particularly chinook, chum, and to a lesser extent pink salmon. Estuaries contain new food sources to support the rapid growth of salmonid smolts and an area in which to undergo physiological adaptation from freshwater to saltwater. The complexity of the healthy nearshore environment provides juvenile salmonids with necessary prey items, including insects falling from marine riparian vegetation, bottom-dwelling crustaceans, and crustaceans that live on marine plants such as eelgrass and kelp. Smolts prefer shallow-water habitats. In particular, habitats that support the detritus-based food web, such as tidal marshes and channels, eelgrass beds, and sand and mud flats, provide a complex system of protection from and opportunities for predators and while allowing juvenile salmonids opportunities for places to rest and forage. As smolts grow larger and begin to move into deeper waters, they rely more heavily on planktonic prey, but some, especially chinook, continue to eat insects that drift out from shore.. Returning adult salmonids use the nearshore as staging areas and safe places to make the physiological transition from saltwater to freshwater.

The physical, chemical, and biological processes that create nearshore and estuarine habitats must be maintained for salmonids. For example, sediment transport provides appropriate substrates for eelgrass and other organisms that contribute essential nutrients to the nearshore environment. Marine riparian vegetation must be sufficient to provide woody debris, nutrients, and insects to these environments .

Common disruptions to these habitats include dikes, shoreline armoring, dredging and filling activities, pollution, and shoreline development. Some of the most pressing problems along urban shorelines are interrupted sediment transport processes, filling of intertidal habitat to support development, removal of LWD, and the loss of marine riparian vegetation.

All salmonid species need adequate flow and water quality, spawning riffles and pools, a functional riparian zone, and upland conditions that favor stability. However, some of these specific needs vary by species, such as preferred spawning areas and gravel. Although some overlap occurs, different salmon species and/or stocks of the same species within a river are often staggered in their use of a particular type of habitat. Some are staggered in time, and others are separated by distance.

Chum and pink salmon use the streams the least amount of time. While Green River-origin pink salmon were thought to have been extirpated during the 1930s, recent observations of adult (Kerwin, 1999) and juvenile (Seiler, 2000) pink salmon indicate either a remnant population or an attempt by straying adult pink salmon from out of the basin to recolonize this basin. Green-River-basin-origin adult pink salmon return at two years of age and typically begin to enter the mainstem river in August and spawn in September and October of odd numbered years. During these times, low flows and associated high temperatures and low dissolved oxygen can be problems. Other disrupted habitat components such as less frequent and shallower pools caused by sediment inputs as well as a lack of canopy from an altered riparian zone or widened river channel can worsen these flows and water quality problems because there are fewer refuges for the adults to hold prior to spawning.

Pink salmon fry in the Green River basin are believed to emerge from their redds around March and migrate downstream to the estuary within a month. The downstream migrant trap located at approximately RM 34.0 has reported pink salmon fry captured as early in the year as March 2000. After a limited rearing time in the estuary, pink salmon migrate to the ocean for a little over a year, until the next spawning cycle. Most pink salmon stocks in Washington State return to the rivers only in odd years. The exception is the Snohomish Basin, which supports both even- and odd-year pink salmon stocks.

In the Green River basin, chum salmon (adults are three to five years in age) are from one run type (fall) but have two stocks. These fall chum adults enter from late October through early December and spawn from mid November through late December. Chum salmon fry emerge from the redds in February and March, and quickly outmigrate to the estuary for rearing. In the estuary, juvenile chum salmon follow prey availability. Later as the food supply dwindles, chum move offshore and switch diets (Simenstad and Salo, 1982).

Chinook salmon have three major run types in Washington State. Spring chinook are typically in their natal rivers throughout the calendar year as juveniles, adults or both. Spring chinook were historically present in the Duwamish/Green River basin and would have entered into freshwater during April or May. However, this run either returns in such low numbers as to be difficult to detect, became extirpated after the initial construction efforts of the Tacoma Headworks Dam in 1911, or were isolated from the basin with the diversion of the White River in 1906. Historically, they would have spawned from July through September and typically in the headwater areas where the higher gradient habitats they prefer exist. There does exist some evidence of early September spawning of chinook salmon but it is unclear if these fish are truly spring chinook or early spawning fall chinook. Incubation would have continued throughout the autumn and winter and generally required more time for the eggs to develop into fry because of the colder temperatures in the headwater areas. Fry would have begun to leave the redds in February through early March. After a short rearing period in the shallow side margins and sloughs, Puget

Sound and coastal spring chinook juveniles begin to leave the rivers to the estuary throughout spring and into summer (August). Juveniles have been found in the Lower Duwamish through September, and may remain in the estuary even longer. Exact outmigration and residence time in any part of the system is variable, controlled by environmental cues, and requires additional investigation for a better understanding of timing and habitat requirements. In the White River spring chinook stock, historically associated with the Green/Duwamish river basin, juveniles exhibit similar rearing characteristics to summer/fall chinook stocks and leave as sub-yearlings. This is indicative of one variety of outmigration strategies commonly used by spring chinook stocks.

Duwamish/Green river basin summer/fall chinook stocks range in spawn timing from late September through December. Juveniles are believed to incubate in the gravel until late January or early February through early March, and outmigration to the estuaries occurs over a broad time period. Typical fall chinook stocks outmigrate from January through August but the complete migratory time period for juvenile Duwamish/Green River fall chinook is not currently known. While some emerging chinook salmon fry outmigrate quickly, most inhabit the shallow side margins, side channels and side sloughs for up to two months. Then, some gradually move into the faster water areas of the stream to rear, while others outmigrate to the estuary. Typically, the Green/Duwamish river basin summer/fall chinook migrate within their first year of life, but a few stocks (Snohomish summer chinook, Snohomish fall chinook, upper Columbia summer chinook) have juveniles that remain in the river for an additional year. There are no data to indicate that there is a large component of Duwamish/Green River basin stock summer/fall chinook juveniles that remain in freshwater for a full year after emerging from the redds, but a few juvenile chinook with this life history characteristic have been captured in the Mill Creek/Mullen Slough subbasin.

Duwamish/Green River chinook use the mainstem Green River, Big Soos Creek, and Newaukum Creek (Williams et al. 1975), as well as Burns Creek (Malcom 1999), Mill Creek (Jones and Stokes 1989), and Springbrook Creek (Malcom 1999) and Crisp Creek (Malcom 1999). The extent of any natural juvenile chinook rearing in non-natal tributary streams is unknown. Fall chinook adults have been observed spawning in the mainstem Green River primarily between RM 24.0 and RM 61.0 (Williams et al. 1975, WDFW Spawning Ground Survey Database). However, recent spawning ground survey observations from 1996 through 1999 inclusive, indicate that the majority of the chinook spawning begins at RM 25.4 (Malcom 1999). The downstream extent of adult chinook spawning appears to vary from year to year. It is unclear what determines the downstream extent but it is likely influenced by environmental factors such as water flow and temperature. The two areas of preferred spawning have been reported from RM 29.6 to 47.0 and from RM 56.0 to 61.0 (Grette and Salo 1986). Because of changing environmental conditions and increased survey efforts, the analysis of the preferred spawning reaches is unclear and ongoing. In 1998, the bulk of the spawning occurred upstream of RM 33, with distinct areas of dense chinook spawning observed and other sections of the river lacking any redds (Muckleshoot Indian Tribe Fisheries Division (MITFD), unpub. data). In 1999, large numbers of redds were located near the confluences of Soos and Icy Creeks with the Green River. Recently, helicopter spawning ground surveys have indicated a large number of redds in the Green River Gorge (WDFW unpub. data; MITFD unpub. Data; Kerwin 1999). The spawn timing for Newaukum Creek summer/fall chinook peaks in October, ranging from September through November. Green-Duwamish summer/fall chinook spawn from early September into early November. Spawning in the mainstem Green River is considered to have ended by 1 November.

Historically, naturally produced adult chinook were present in the mainstem Green River and some tributaries upstream of the City of Tacoma's diversion dam located at RM 61 (Riseland 1913). Juvenile chinook produced by natural spawning have been recovered from Soos and Covington Creeks and adult chinook have been observed at the entrance to Lake Sawyer.

The onset of coho salmon spawning is tied to the first significant fall freshet. Green/Duwamish river basin coho stocks typically enter freshwater from September to early December, but have been observed as early as late-July and as late as mid-February (MIT unpublished data). They often mill near the river mouth or in lower river pools until the fall freshets occur. Spawning usually occurs between November and early February, but is sometimes as early as mid-October. Spawning typically occurs in tributary streams. High stormwater flows and sedimentation in these tributaries can suffocate eggs. As chinook salmon fry exit the shallow low-velocity rearing areas, coho fry utilizes those same areas for the same purpose. As they grow, juveniles move into faster water and disperse into tributaries and areas which adults cannot access (Neave 1949). Pool habitat is important not only for returning adults, but for all stages of juvenile development. Preferred pool habitat includes deep pools with riparian cover and woody debris.

All Green/Duwamish river basin coho juveniles remain in the river for a full year after leaving the gravel nests, but during the summer after early rearing, low flows can lead to problems such as a physical reduction of available habitat, increased stranding, decreased dissolved oxygen, increased temperature, and increased predation. Juvenile coho are highly territorial and can occupy the same area for a long period of time (Hoar, 1958). The abundance of coho can be limited by the number of suitable territories available (Larkin, 1977). Streams with more structure (logs, undercut banks, etc.) support more coho (Scrivener and Andersen, 1982), not only because they provide more territories (useable habitat), but they also provide more food and cover. Large wood also assists in the retention of salmon carcasses by adding habitat complexity in the form of pools where these carcasses may settle out and add nutrients for stream productivity. There is a positive correlation between their primary diet of insect material in stomachs and the extent the stream was overgrown with vegetation (Chapman, 1965). In addition, the leaf litter in the fall contributes to aquatic insect production (Meehan et al., 1977).

In the autumn as the temperatures decrease, the juvenile coho move into deeper pools, hide under submerged logs, overhanging and submerged tree roots, and undercut banks (Hartman, 1965). The fall freshets redistribute them (Scarlett and Cederholm, 1984), and over-wintering generally occurs in available side channels, spring-fed ponds, and other off-channel sites to avoid high stream velocities associated with winter floods (Peterson, 1980). The lack of side channels and small tributaries may limit coho survival (Cederholm and Scarlett, 1981). As coho juveniles grow into yearlings, they become more predatory on other salmonids. Green/Duwamish river basin origin coho begin to leave the river over a year after emerging from their gravel nests with the peak outmigration occurring in early May. Coho use estuaries primarily for interim feeding while they adjust physiologically to saltwater.

Sockeye salmon have a wide variety of life history patterns, including the landlocked populations of kokanee, which never enter saltwater. The origin of adult sockeye observed spawning in the

Green/Duwamish river basin is not known. It is hypothesized that the adult sockeye spawning in the Duwamish/Green River are: (1) strays from outside the basin; (2) a riverine form of sockeye or; (3) some combination of both. The first trajectory is thought to be the most likely because of the close proximity of Lake Washington and its associated sockeye stocks. However, because sockeye adults are observed annually in rivers throughout Puget Sound, some professional fishery biologists theorize that there are small populations of riverine sockeye throughout western Washington rivers. Adult sockeye are observed annually in low numbers in the spawning in the Green/Duwamish river Basin.

After sockeye fry emerge from the gravel, the typical life history trajectory is that most migrate to a lake for rearing, although some types of fry migrate to the sea and others rear in mainstem rivers. Lake rearing ranges from 1-3 years. Because a lake rearing environment is not present in the Green River any sockeye juvenile and resultant smolt production would have to be riverine in origin. Riverine sockeye are found in some river systems in Alaska where they rear in larger mainstem rivers.

Steelhead have one of the most complex life history patterns of any anadromous Pacific salmonid species (Shapovalov and Taft, 1954). In Washington, there are two major run types, winter and summer steelhead. Green/Duwamish river basin winter steelhead adults begin river entry in a mature reproductive state in December and generally spawn from February through May. The Green/Duwamish river basin also supports a hatchery origin summer steelhead run. Specific run and spawn timing for summer-run steelhead is unknown but generally is May through October and February through April respectively.

Naturally produced juvenile winter steelhead can either migrate to sea or remain in freshwater as a resident rainbow trout. The vast majority of juvenile steelhead smolt and migrate to saltwater. Duwamish/Green River basin origin steelhead usually spend 1-3 years in freshwater, with the greatest proportion spending two years. Because of this, steelhead rely heavily on the freshwater habitat and are present in streams all year long.

The presence or absence of self sustaining bull trout populations in the Green/Duwamish river Basin are not well documented and are discussed in detail elsewhere in this report. Bulltrout-Dolly Varden stocks are also very dependent on the freshwater environment, where they reproduce only in clean, cold, relatively pristine streams. Within a given stock, some adults remain in freshwater their entire lives, while others migrate to the estuary where they stay during the spring and summer. They then return upstream to spawn in late summer. Those that remain in freshwater either stay near their spawning areas as residents, or migrate upstream throughout the winter, spring, and early summer, residing in pools. They return to spawning areas in late summer. In some stocks juveniles migrate downstream in spring, overwinter in the lower river, then enter the estuary and Puget Sound the following late winter to early spring (WDFW, 1998). Because these life history types have different habitat characteristics and requirements, bulltrout are generally recognized as a sensitive species by natural resource management agencies. Reductions in their abundance or distribution are inferred to represent strong evidence of habitat degradation.

All of the salmonid species have similar habitat needs such as unimpeded access to spawning habitat, a stable incubation environment, favorable downstream migration conditions (adequate flows in the spring), and a healthy estuarine environment. Some species, such as chinook, pink and chum rely heavily on the estuary for foraging, growth, and physiological transition that requires good estuary habitats.

In addition to the above-described relationships between various salmon species and their habitats, there are also interactions between the species that have evolved over the last 10,000 years such that the survival of one species might be enhanced or impacted by the presence of another. Pink and chum salmon fry are frequently food items of coho smolts, cutthroat, bull trout, and steelhead (Hunter, 1959). Chum fry have decreased feeding and growth rates when pink salmon juveniles are abundant (Ivankov and Andreyev, 1971), probably the result of occupying the same habitat at the same time (competition). Salmon carcasses can provide a direct and indirect food resource for the same or other salmonid species. These are just a few examples.

The Green/Duwamish river basin is home to several salmonid species, which together, rely upon freshwater and estuary habitat the entire calendar year. As the habitat and salmon review indicated, there are complex interactions between different habitat components, between salmon and their habitat, and between different species of salmon. Just as habitat dictates salmon types and production, salmon contribute to habitat and to other species. Specific information about individual runs and stocks is contained the next chapter, “Current Salmonid Population Conditions in the Green/Duwamish River Basin.”

PART I: INTRODUCTION

3. Current and Historic Salmonid Population

3. CURRENT AND HISTORIC SALMONID POPULATION

OVERVIEW OF HISTORIC NATURAL SPAWNING SALMONID POPULATION

Historically, the Duwamish/Green River basin was comprised of a number of subbasins that in the last 100 years been diverted out of the basin. Today, the Duwamish/Green River basin has been extensively altered ecologically and physically. Historically, the White River is believed to have moved between the Puyallup and Green River drainages. During periods of high flows, the White River utilized the Stuck River as an overflow channel and some or all of the flow was transferred to the Puyallup River. However, the movement of water and the size of the basin began to change dramatically, first with the permanent diversion of the White River to the Puyallup drainage in 1906 (natural and man-induced); followed by the diversion of Lake Washington and Cedar River to the Ship Canal in 1916, the construction of the Tacoma Diversion Dam in 1911 and construction of Howard Hansen Dam in 1961. All of these contributed to the elimination of access by anadromous and resident fish to many of the habitats historically present in the basin. These changes have reduced the Green River watershed to approximately 30% of its historical size.

There is very little reliable historical sources of information on anadromous and resident salmonid species abundance in the Duwamish/Green River basin. Historically, runs of chinook (spring and summer/fall stocks), pink, coho, chum salmon, winter steelhead and cutthroat trout were present in the Duwamish/Green River basin. Summer steelhead were also likely present in low numbers. There is limited evidence that sockeye salmon spawn and rear (Jeanes et al 2000).

The only historic data for chinook and coho escapement comes from early hatchery records of the two facilities that began operation in the basin shortly after 1900. Fuerstenberg et al (In Draft 1999) provided a coho salmon escapement number of 36,741 adults annually between 1938 – 1942 and 12,500 for the years between 1987 - 1991, however no citation for these numbers was provided and the Muckleshoot Indian Tribe has not agreed to these figures (R. Malcom pers. comm.).

In response to the construction of the City of Tacoma Diversion Dam in 1911, a hatchery facility, that was actually an egg taking station, was constructed immediately downstream of the Tacoma Headworks Dam that same year. Sometimes referred to as Hatchery Number 2, this facility was closed in 1921. The hatchery records (HSP 1) provide one piece of information into the historic run sizes upstream of the present day Tacoma Headworks project and Howard Hanson Dam.

HSP 1: Numbers of chinook, coho and steelhead females spawned at the Green River Eyeing Station 1911 – 1920 (Source: Grette and Salo 1986)

Reporting Period	Chinook	Coho	Steelhead	Comments
4/1/11 – 3/31/12	0	2248	0	
4/1/12 - 3/31/13	136	3117	1308	
4/1/13 – 3/31/14	116	2757	0	New trap constructed
4/1/14 – 3/31/15	87	604	254	Low water levels
4/1/15 – 11/30/15	101	341	150	
12/1/15 – 11/30/16	61	795	247	
12/1/16 – 3/31/17	0	738	0	
4/1/17 – 3/31/18	280	146	61	
4/1/18 – 3/31/19	259	96	49	
4/1/19 – 3/31/20	40	430	134	
4/1/20 – 3/31/21	16	785	254	

Almost certainly there were inefficiencies in the operation of this eyeing station trap and the actual run size was probably larger. Prior to 1913 the trap was located in the stilling basin of the dam and was believed to be less than successful. In response to the lack of success, during 1913, a new concrete trap was constructed on one of the wings of the dam and at the time was deemed quite successful (Darwin 1916). However, the dam and associated trap almost certainly resulted in fish that were reluctant to enter the trap to spawn downstream of the facility. These fish would have been destined for upriver locations and were not counted.

The construction of the new trap in 1913 is important for at least two reasons. Darwin (1916) stated that: "… every salmon that ascended the stream has been taken …". It is assumed that this statement means every female is spawned and thus counted in the hatchery records presented in Table 1 above. If that assumption is not correct then it would introduce an additional downward bias in counts of fish destined for upriver production. Those records only reflect females spawned and do not account for any mortality. The lack of counting these mortalities almost certainly causes a downward bias in the total run size.

Secondly, the timing of the trap construction may have precluded steelhead trapping during the time period of 4/1/13 to 3/31/14. Winter run steelhead typically spawn beginning in mid-March with the majority spawning after April 1. This timing issue may account for the lack of a steelhead egg take during 1913/14. The current operations of the temporary trap at the Tacoma Headworks facility still reflect that fact as this trap is not put in the river until March 1 and removed in late May or early June.

Based on the numbers in Table 1, Grette and Salo (1986) determined escapement estimates for chinook, coho and steelhead and those numbers are presented in HSP 2 below.

HSP 2: Escapement estimates of coho, chinook and steelhead upstream of Tacoma Headworks project prior to project construction (Source: Grette and Salo 1986)

Species	Range of Adult Returns	Escapement Estimate
Chinook	174-272	No estimate
Coho	4,496 – 6,234	5,400 – 6,200
Steelhead	500-2,616	500 – 2,600

Grette and Salo (1986) determined that the chinook spawned at the Tacoma Headworks project were a spring chinook stock. Certainly, the life history trajectory of spring chinook stocks is to utilize the headwater areas of river systems for spawning and early rearing of juveniles. They felt that the presence of the weir in the lower river at the confluence with Soos Creek captured the summer/fall chinook run. This conclusion is important in that most professional fishery biologists feel that spring chinook are either extinct or returning in such low numbers as to not constitute a distinct stock in the Green River. This is also important from the perspective of holding adult chinook. Unlike summer/fall chinook which only have to be held a matter of weeks for sexual maturation, spring chinook have to be held for up to several months. This longer holding period likely induces a higher mortality in the holding pond.

Fuerstenberg et al (In Draft) provided a chinook salmon escapement number of 55,197 adults annually between 1938 – 1942 and 10,3000 for the years between 1987 - 1991, however no citation for these numbers was provided and the Muckleshoot Indian Tribe has not agreed to these figures (R. Malcom pers. comm.).

Additionally, Grette and Salo (1986) placed some doubt that the numbers of chinook returning to the Diversion Dam were similar before and after construction. They based this doubt on the amount of habitat available upstream of the project and poaching of adult salmon in the pools below the diversion dam (R. Wolschlagel, pers. comm. contained in Grette and Salo 1986).

Additional insight into escapement records comes from Riseland (1913). He provides some data on eggs taken from the Green River at the location of the then newly constructed Tacoma Headworks Dam and insight of historic anadromous populations that would have migrated upstream of this location. Those escapement estimates are shown in HSP 3.

HSP 3: Escapement estimates for spring chinook, coho and winter steelhead to Upper Green River subbasin pre-1911 (Source: Riseland 1913)

Species	Range
Spring Chinook	150 - 300
Coho	9,000 – 25,000
Winter Steelhead	500 – 2,500

Finally, Chapman (1981) developed estimated smolt and adult returns for chinook, coho and steelhead upstream of the Headworks. In the development of these estimates he assumed pristine habitat conditions and the absence of HHD. Those estimates are shown below in HSP 4.

HSP 4: Estimated chinook, coho and winter steelhead smolts produced and adult returns under pristine conditions for the upper Green River subbasin (Source: Chapman 1981)

Species	Smolts produced	Adult Escapement
Chinook	128,644	1,286
Coho	213,516	4,270
Winter Steelhead	20,079	437

Sockeye salmon adults are reported annually in the vicinity of the Headworks. Estimates range from 100 to 400 adults. It is unknown if these fish are successfully reproducing. Eagle Lake (sometimes referred to as Enapooh Lake) is the only lake of sufficient size (53.2 surface acres) to have historically provided a rearing opportunity for sockeye juveniles in this subbasin. However, it is no longer accessible to anadromous fish.

A comparison of the escapement and predicted returns from the individual sources above is shown in HSP 5.

HSP 5: A comparison of predicted escapement estimates and returns of adult chinook, coho and steelhead from three historical perspectives for the Green River upstream of the Tacoma Headworks project.

Species	Grette and Salo	Riseland	Chapman
Chinook	No estimate	150 - 300	1,286
Coho	5,400 – 6,200	9,000 – 25,000	4,270
Steelhead	500 – 2,600	500 – 2,500	437

The first anadromous salmon hatchery facility in the Green River basin, the Green River Hatchery State Fish Hatchery (SFH) on Soos Creek was constructed in 1904. Egg takes had begun on Soos Creek in 1903 but it is not clear where those eggs were taken. Run size, harvest and spawning escapement data for the Green River (and other Puget Sound drainages) chinook and coho are unavailable prior to the mid-1960s. However, early trap records at the Soos Creek SFH do provide some insight into returns of these species. A weir was constructed across Soos Creek beginning in 1903 for the purpose of obtaining hatchery broodstock and supplying the Soos Creek SFH with coho and chinook eggs. Grette back calculated the numbers of female chinook and coho salmon spawned and Salo (1986) based on egg take and literature obtained fecundity averages. Those calculations show a low of 192 female coho spawned in 1903 (the first year of operation) to a high of 6,013 in 1924. Numbers of adult female chinook spawned range from a low of 192 in 1903 to a high of 7,308 in 1935. It is highly probable that escapement for these two species was higher because the weir often washed out during October when leaf fall along with heavy rains would have made maintaining the weir structure very difficult (Beckler 1967).

Total escapement estimates for winter steelhead prior to the 1977-78 (WDFW and WWTIT 1992) run year are not available. Run size and escapement estimates of winter steelhead to the upper portions of the Green River basin were reported on earlier in this chapter. Fuerstenberg et al (In Draft) provided a winter steelhead escapement number of 4,400 adults annually between 1938 – 1942 and 1,600 for the years between 1987 - 1991, however no citation for these numbers was provided and the Muckleshoot Indian Tribe has not agreed to these figures (R. Malcom pers. comm.).

Summer steelhead in the Green River are near the edge of the geographic range for this species. The run size and estimated escapement of this species is not available. The best indication of a historic run comes from Washington Department of Fish and Wildlife (formerly Washington Departments of Fisheries and Game/Wildlife) harvest records. Harvest was very small prior to the initiation of a hatchery program in the mid-1960's. Those harvest numbers are shown in HSP 6.

HSP 6: Historic sport catches of summer-run steelhead in the Green River 1962 – 1982.

Year	Catch
1962	3
1963	44
1964	0
1965	3
1966	53
1967	163
1968	254
1969	221
1970	180
1971	277
1972	1794
1973	1781
1974	647
1975	1014
1976	1722
1977	1664
1978	2477
1979	1196
1980	1528
1981	3398
1982	1934

Note: Catch numbers prior to 1974 are not corrected for non-response bias, resulting in a value that is probably higher than actual.

Historic run sizes and escapement estimates for chum salmon are more difficult to quantify. Williams (1975) reported an average annual escapement for the Duwamish/Green River basin of 11,300 for the years 1966 – 71 inclusive. There is no terminal area harvest data available prior to 1974 that would assist in determining run size to the Duwamish/Green River. Spawning ground counts for chum salmon are scarce. From the available information we were not able to determine historic run sizes or escapement estimates. Fuerstenberg et al (In Draft) provided a chum salmon escapement number of 12,750 adults annually between 1938 – 1942 and 3,000 for the years between 1987 - 1991, however no citation for these numbers was provided and the Muckleshoot Indian Tribe has not agreed to these figures (R. Malcom pers. comm.).

Pink salmon have historically been present in low numbers in the lower and middle Green River basin. Williams (1975) stated that pink salmon have been extinct in the Green River basin since the 1930's but provided no insight into that determination. Grette and Salo (1986) cited Williams (1975) and stated that they have been "… eliminated from the drainage…". They also stated that an occasional pink salmon adult is captured in mainstem Green River fisheries. Fuerstenberg et al (In Draft) provided a pink salmon escapement number of 1,000 adults in odd numbered years between 1938 – 1942, however no citation for this number was provided and the Muckleshoot Indian Tribe has not agreed to these figures (R. Malcom pers. comm.). Historic spawning ground surveys for pink salmon in the Green River basin are scarce and do not provide enough data to assist in escapement determination. Indeed for the Green River basin there are only 14 entries from three streams in a database that contains approximately 150,000 entries from WRIAs 1 – 19. The current status of this species is discussed further elsewhere in this report.

Historic data concerning coastal cutthroat trout in the Duwamish/Green River basin is scarce. Williams (1975) indicated the presence of cutthroat trout in this basin but provided no abundance or life history information. Cummins (1980) stated that the run and harvest is small in comparison to other river systems in northern Puget Sound. Only small numbers of cutthroat are reported captured during sampling in the Duwamish Estuary (Meyer et al 1981, Weitkamp and Campbell 1980, Weitkamp and Schadt 1982).

OVERVIEW OF CURRENT SALMONID POPULATION

The 1992 Washington State Salmon and Steelhead Inventory (SASSI) (WDFW and WWTIT, 1994) listed the stock status of Green River summer/fall chinook, Crisp Creek fall chum, Soos Creek coho, both summer and winter steelhead stock as healthy. The stock status of Green River fall chum, sockeye, and bull trout were listed as unknown. Pink salmon are believed by many to have been extirpated in WRIA 9 and were not identified as a stock present in this system. However, adult pink salmon have been observed spawning in the mainstem and juvenile pink salmon have been captured. A summary of salmon and steelhead usage in major subbasins is presented in table CSP-1. The Green River winter steelhead, bull trout and coastal cutthroat trout are defined as a native stock. The origin of Green River sockeye salmon is unknown. Both chinook stocks, Soos Creek coho are of a mixed stock origin while Crisp Creek fall chum, early timing winter steelhead and summer steelhead are of a non-native origin. The National Marine Fisheries Service (NMFS) includes the naturally produced fall chinook stock population in the Puget Sound Evolutionary Significant Unit (ESU) and has listed that ESU as Threatened under the Endangered Species Act. There have only been occasional observations of adult spring chinook in this system. The stock status of Green River native winter steelhead was listed as healthy in SASSI, but recent population trends indicate that may be optimistic.

Table CSP-1. Salmon Species and Stocks Found in the Green/Duwamish (SASSI 1994). The NMFS and USFWS listed or proposed Endangered Species Act (ESA) listing status are also shown as of January 2000.

Stock[1]	Stock Origin[2]	Production Type[3]	Stock Status (SASSI)	ESA Status (NMFS & USFWS)
Green/Duwamish River Summer/Fall Chinook	Mixed[4]	Composite[7]	Healthy	Listed as Threatened
Newaukum Creek Summer/Fall Chinook	Mixed	Wild[8]	Healthy	Listed as Threatened
Green/Duwamish River Fall Chum	Mixed	Composite	Unknown	Not Warranted
Crisp (Keta) Creek Fall Chum	Non-native[5]	Cultured [9]	Healthy	Not Warranted
Green River/Soos Creek Coho	Mixed	Composite	Healthy	Candidate
Newaukum Creek Coho	Mixed	Composite	Depressed	Candidate
Green/Duwamish River Summer Steelhead	Non-native	Composite	Healthy	Not Warranted
Green/Duwamish River Winter Steelhead	Native[6]	Wild	Healthy	Not Warranted
Green/Duwamish River Early Winter Steelhead	Non-native	Cultured	Healthy	Not Warranted
Green River Pink	Native	Wild	Unknown But Presumed Depressed	Not Warranted
Green River Sockeye[10]	Unknown	Wild	Unknown	Uncertain
Green River Bull Trout[11]	Native	Wild	Unknown	Listed as Threatened
Green River Coastal Cutthroat Trout[12]	Native	Wild	Unknown	Protection Unnecessary At This Time

Notes

As defined in WDFW and WWTT (1994), the fish spawning in a particular lake or stream(s) at a particular season, which fish to a substantial degree do not interbreed with any group spawning in a different place, or in the same place at a different season.

The genetic history of the stock

The method of spawning and rearing that produced the fish that constitutes the stock.

A stock whose individuals originated from commingled native and non-native parents, and/or by mating between native and non-native fish (hybridization) or a previously native stock that has undergone substantial genetic alteration.

A stock that has become established outside of its original range

An indigenous stock of fish that have not been substantially impacted by genetic interactions with non-native stocks, or by other factors, and is still present in all or part of its original range.

A stock sustained by both wild and artificial production.

A stock that is sustained by natural spawning and rearing in the natural habitat, regardless of parentage (includes native)

A stock that depends on spawning, incubation, hatching, or rearing in a hatchery or other artificial production facility.

Not listed in WDFW and WWTT (1994).

Listed in WDFW SaSI (1998).

WDFW (2000).

GREEN/DUWAMISH RIVER BASIN SUMMER/FALL CHINOOK SALMON POPULATION TRENDS

Chinook salmon in the Green River consist primarily of summer/fall run fish. Historically, a spring run also occurred in the watershed but re-routing of the White River to the Puyallup drainage in 1906 (natural and man-induced), re-routing of Lake Washington and Cedar River to the Ship Canal in 1916, construction of the Tacoma Diversion Dam in 1913 and construction of Howard Hansen Dam in 1961 eliminated access to much of the headwater habitat typically needed by spring chinook salmon in this region (Grette and Salo 1986). These changes reduced the Green River watershed to approximately 30percent of its historical size. Presently, nearly all of the natural chinook production occurs in the mainstem Green River below the Tacoma Diversion Dam, Soos Creek, and Newaukum Creek. Chinook in WRIA 9 are separated into two stocks (WDFW and WWTIT, 1994), the Green/Duwamish and the Newaukum Creek summer/fall stocks. Escapement for the Green/Duwamish River summer/fall chinook stock from 1986 to 1997 is shown in Figure CSP-1, averaged 6,031 and ranged from 2,027 to 10,059. Between those dates the escapement of naturally spawning fish has varied substantially. Although spring chinook salmon are occasionally found in the Green River it is not known if these fish constitute a self-sustained run.

Chinook salmon returning to the Green River have been a mixture of natural spawning and hatchery chinook salmon since approximately 1904 when the first hatchery fish returned to the Green River Hatchery on Soos Creek. Harvest and spawning escapement data for the Green River (and other Puget Sound drainages) are unavailable prior to the mid-1960s. The only index of chinook salmon returns to Puget Sound during the early 1900s is commercial and sport harvests in the Strait of Juan de Fuca and Puget Sound. However, these data are confounded by the presence of chinook salmon destined for British Columbia and the interception of Puget Sound-bound chinook in Washington coastal troll and other interception fisheries.

As a result of recent efforts by the WDFW and tribes, more accurate records of chinook spawning escapement and stock-specific harvests are available since 1968. Enhanced accounting of chinook escapements and runs in Puget Sound drainages arose, in part, as a response to the 1976 Boldt (U.S. vs WA.) decision which influenced managers to switch from harvest rate based management to spawning escapement based management. However, the harvest component in the stock-specific WDFW run reconstruction database is limited to commercial harvests (mainly net harvests) in Puget Sound (treaty and non-treaty Indian). Sport and commercial fishermen in British Columbia harvest many chinook salmon having their origin in Puget Sound. To account for Green River chinook salmon harvested in fisheries other than commercial net harvests in Puget Sound, NRC (1999) integrated annual distributions of total mortalities (including incidental mortalities) associated with each fishery in each geographic region (PSC 1999) with the WDFW harvest data to reconstruct total annual runs of chinook salmon returning to the Green River. The results of this run reconstruction are described below for natural spawning and hatchery summer/fall chinook salmon.

The reconstructed run estimates for Green River chinook salmon are subject to a variety of measurement errors, which are typical of fishery estimates such as these. For example, currently the spawning escapement in the Green River is estimated by counting chinook redds (spawning nests) in a portion of the basin, expanding redds counts by a factor of 2.5 to account for numbers of fish per redd, then expanding this estimate of spawning fish to the entire basin based on an estimate of total habitat believed to support spawning chinook salmon (Smith and Castle 1994). For mainstem Green River, the latter expansion factor is 2.6, indicating that most of the spawning grounds are not sampled each year. This expansion factor is currently under review and the reanalysis may lead to somewhat lower spawning escapement estimates (Cropp, 1999). Spawning escapement estimates include hatchery strays, a fact that leads to overestimation of the "natural" chinook run produced by naturally spawning parents. Ongoing efforts to remove this bias are discussed below. The most accurate component of fishery statistics is commercial harvest, but significant error may occur when allocating the harvest to the various watersheds in Puget Sound and British Columbia using the Fishery Regulatory Assessment Modeling (FRAM) and Pacific Salmon Commission models.

For this report, we describe Green River chinook runs returning to the hatcheries and to the spawning grounds. The natural spawning population includes hatchery salmon that stray to the spawning grounds. Thus, "natural" chinook, which are produced by naturally spawning parents (wild and hatchery origin), are overestimated to the extent that hatchery chinook stray to the spawning grounds. Because the WDFW and MITFD run reconstruction approach utilizes the ratio of chinook returning to the hatchery compared to the spawning grounds to estimate hatchery versus "natural" chinook salmon in harvests, the true natural run is overestimated and the hatchery run is underestimated. The confounding effect of hatchery strays on natural chinook production estimates in systems such as the Green River was identified in the NMFS status review as a key concern leading to the listing of Puget Sound chinook salmon (Myers et al. 1998).

For this report, we use the term "natural" chinook salmon to mean fish produced by natural spawning parents that return to the spawning grounds plus hatchery fish that stray to the spawning grounds. This terminology is used because existing WDFW and MITFD escapement data can not distinguish between true natural fish and hatchery strays. Ongoing efforts are being made to use coded-wire-tag recoveries in the hatcheries and spawning grounds to estimate stray rates. With the initiation of the "Massmarking" of hatchery produced chinook beginning with brood year 1999 the ability to distinguish on the spawning grounds between hatchery produced and natural produced fish should accomplished beginning in 2003.

NATURALLY PRODUCED GREEN RIVER ORIGIN CHINOOK SALMON

During 1968-1996, the estimated naturally produced run of summer/fall Green River chinook salmon ranged from 5,600 in 1973 to 41,000 in 1983 and averaged 17,400 fish (Figure CSP-2). Run size tended to be higher during recent years (1983-1996) compared to earlier years (1968-1982), indicating the downward trend common to other Puget Sound stocks is not evident among "natural" Green River chinook salmon. The trend of greater runs during recent years compared to earlier years is also evident from WDFW's estimated commercial net harvests of Green River "natural" chinook and spawning ground escapement estimates (Figure CSP-2).

WDFW and the Muckleshoot Indian Tribe (MIT) estimates the spawning population of chinook salmon in the Green River by counting chinook salmon redds (spawning nests) within selected stream reaches, expanding these redd counts to unsurveyed spawning habitat, then expanding redd counts to the total spawning population. The spawning escapement goal of 5,800 natural spawners was established in the mid-1970s using average escapement of wild and hatchery strays during 1965-1976 (Ames and Phinney 1977). As shown in Figure CSP-1, the estimated spawning escapement during 1986-1997, including unknown hatchery strays, averaged 5,700 fish and it exceeded the goal during 12 (40 percent) of 30 years (Figure CSP-1). During the past 10 years (1988-97), spawning escapements have been relatively large (avg. 7,280 fish) and escapements have exceeded the goal during 7 (70 percent) of 10 years.

It is worth noting that escapements greater that 6,060 fish tended to produce greater returns, on average, compared to somewhat smaller escapement. This suggests the risk of producing small returns is reduced when allowing somewhat larger escapements. Large escapements leading to overcompensation (declining returns from large escapements) was not clearly evident within the range of observed escapements, indicating the risk of reduced returns at escapements less than 10,000 fish is probably low.

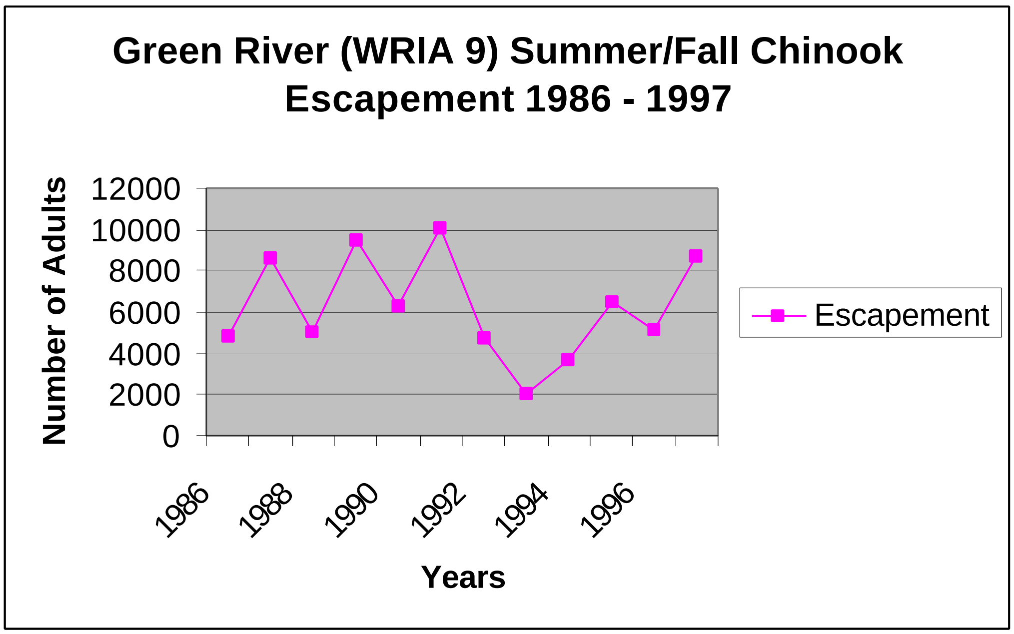
This run reconstruction analysis of “natural” chinook salmon includes stray hatchery chinook salmon that spawned in the Green River. Hatchery chinook salmon on the spawning grounds may have originated from fish released from the hatcheries or from off-station releases such as those at Icy Creek and above Howard Hansen Dam. The implication is that the natural run, harvest, and escapement of Green River chinook salmon is overestimated to the extent that hatchery fish contribute to natural spawners on the Green River. Hatchery strays affect harvest estimates of natural chinook because the run reconstruction approach used by WDFW and the MIT is dependent on the estimated escapement to the spawning grounds. For example, if 30 percent of the chinook escaping to the river return to the spawning grounds and 70 percent return to hatcheries, then WDFW and MIT assumes 30 percent of the harvest of Green River chinook (hatchery and wild) is allocated to the “natural” run and 70 percent to the hatchery run.

A modeling exercise is underway to reconstruct wild chinook runs and escapements based on a range of stray rates for cultured chinook salmon in the Green River (NRC 1999). The analysis will use recoveries of coded-wire-tagged hatchery salmon recovered on the spawning grounds and hatcheries to estimate stray rates. This analysis removes stray hatchery fish from escapement and harvest estimates during the year of return and it removes estimates of future production produced by stray salmon spawning in the river. Preliminary results suggest that while the revised wild chinook runs and escapements are smaller than those reported above, the productivity of the system, in terms of adult returns per spawner, remains relatively high.

As previously stated, the naturally spawning component of the Green River chinook run contains a mixture of wild and hatchery chinook. The major question pertaining to the status of Green River chinook is the contribution of hatchery chinook to the natural escapement. Draft run-reconstruction information for the years 1989 – 1997 inclusive indicates approximately 56 percent (range: 25 to 83 percent) of the natural escapement in the mainstem Green River of being from hatchery reared and released fish (Cropp, pers. comm.1999). It is not possible to determine to what extent the remaining approximate 40 percent of the mainstem Green River escapement has its ancestry from hatchery origin fish that have spawned for one or more generations in the wild. For the same time period, in Newaukum Creek, the origin of adult chinook is approximately 45 percent (range: 15 to 79 percent) of hatchery origin (Cropp 1999). Additionally, draft data, for the same time period, indicates approximately 39 percent (range: 1 to 76 percent) of the adult chinook returning to the hatchery rack are progeny of natural spawning adults. Newaukum and Soos Creek data is probably quite reliable since sampling rates are relatively high (30 percent and 98 percent respectively) (Cropp 1999). The Green River mainstem sampling rate was roughly 4 percent due to difficulties in locating samples in the large river and is probably less reliable. Sampling efforts in the mainstem Green River were increased beginning in 1998 but the data has not yet been analyzed.

The chinook spawning escapement estimates in Figure CSP-1 include hatchery strays, a fact that leads to overestimation of the "wild" chinook run produced by naturally spawning parents. If large numbers of hatchery strays are included in SASSI escapement estimates, the SASSI status designation for this population could be changed to reflect that contribution.

Figure CSP-1: Green River (WRIA 9) Summer/Fall Chinook Escapement 1986 - 1997.



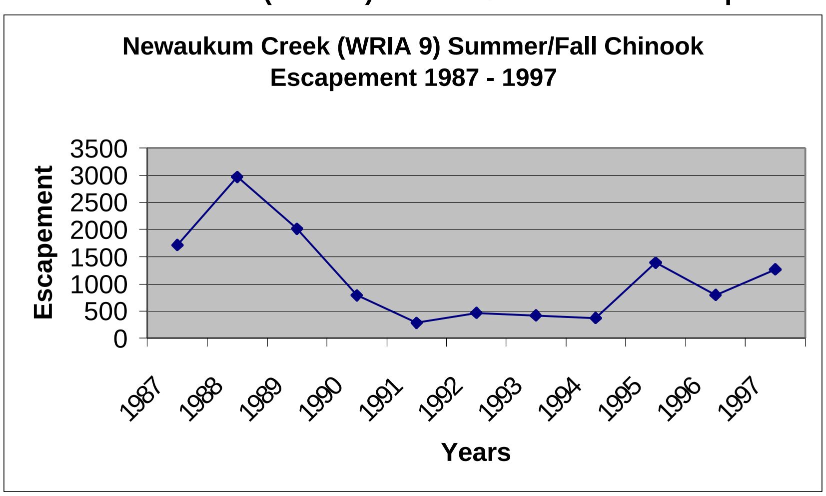
Newaukum Creek summer/fall chinook escapement from 1987 to 1997 is shown in Figure CSP-2 and averaged 1,135 with a range from 285 to 2,968.

The Green/Duwamish River Basin chinook stock is considered a composite with contributions from hatchery production and natural production. Newaukum Creek fall chinook production is considered wild (WDFW and WWTIT 1994) and is dependent on natural production. Escapement for the Green/Duwamish River summer/fall chinook stock from 1986 to 1997 is shown in Figure CSP-1, averaged 6,031 and ranged from 2,027 to 10,059. Between those dates the escapement of naturally spawning fish has varied substantially. For both stocks, escapement estimates are dependent on redd counts in specified river/creek reaches and expanded by a factor to reflect total escapement to the basin. The counts are accurate for the areas surveyed, but may not be reflective of total escapement (WDFW and WWTIT 1994). Recently, some comparisons of escapement estimates based on a comparison of different methodologies have challenged this assumption. For example, when using a methodology called “Peak-redds-to-total-redds”, which has been the traditional methodology of choice on the Green River, the mainstem chinook escapement in 1997 was 11,236 fish. If the escapement estimate is calculated using a methodology called the “Index Expansion” method as used for calculating steelhead escapement then the chinook escapement for 1997 is 5,808 fish. The difference between the two estimates is 5,428 fish (49 percent).

Newaukum Creek summer/fall chinook escapement from 1987 to 1997 is shown in Figure CSP-2 and averaged 1,135 with a range from 285 to 2,968. Based on coded wire tag (CWT) recoveries from adult chinook in Newaukum Creek, Newaukum Creek chinook escapements are strongly influenced from hatchery production strays from the Green River SFH and Icy Creek Rearing Ponds. The extent to which strays from mainstem Green River production are present in Newaukum Creek is unknown. An examination of CWT data from Newaukum Creek indicates that chinook straying from hatchery production into Newaukum Creek provides the majority of chinook spawning population in Newaukum Creek. SASSI (WDFW and WWTIT 1994) listed Newaukum Creek chinook as a separate stock but do to the extent of hatchery straying, geographic proximity of Soos Creek SFH and the Icy Creek SFH it is likely that chinook spawning in Newaukum Creek are part of the same stock as the Green River chinook.

Spring chinook were historically present in the Green/Duwamish River. However this run either returns in such low numbers as to be difficult to detect or became extinct after the diversion of the White River in 1906 and the blockage of the mainstem Green River by the Tacoma Headworks Dam in 1913. These adult spring chinook would have spawned from July through September and typically in the headwater areas where higher gradient habitat exists. There does exist some evidence (R. Malcom 1999) of early September spawning chinook in the higher reaches of the mainstem Green River, but it is unclear if these fish are truly spring chinook or early spawning fall chinook.

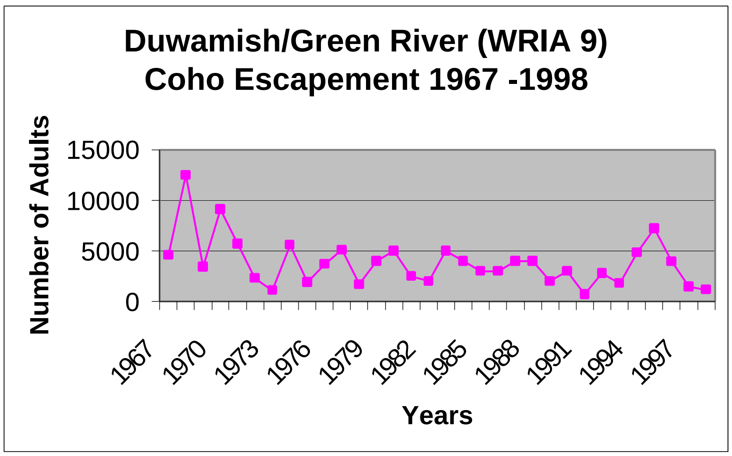
Figure CSP-2: Newaukum Creek (WRIA 9) Summer/Fall Chinook Escapement 1987 - 1997.



GREEN/DUWAMISH RIVER BASIN COHO SALMON POPULATION TRENDS

The coho salmon that enter the Green/Duwamish River basin, WRIA 9, are separated into two stocks (WDFW and WWTIT, 1994), Green/Duwamish and Newaukum Creek stocks. Escapement estimates for the Green/Duwamish River stock from 1967 to 1998 are shown in Figure CSP-3, averaged 3,816 and ranged from 700 to 12,500. Of particular interest is that significant differences exist in spawn timing between these stocks that might be indicative of genetic differences. Coho returning to the Green River typically spawn to mid-November. Newaukum Creek coho may spawn into mid-January (WDFW and WWTIT 1992, WDFW Spawning Ground Survey Database).

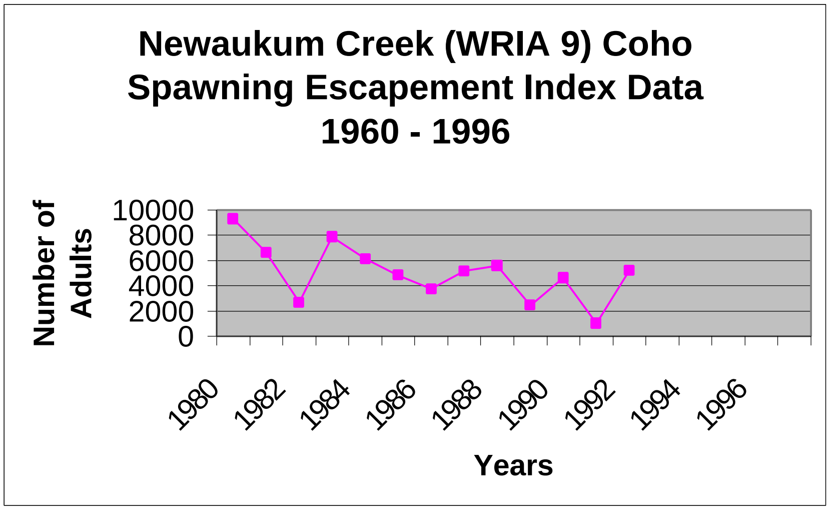
Figure CSP-3: Green/Duwamish River (WRIA 9) Coho Escapement 1967 - 1998.



Newaukum Creek is a left-bank tributary that joins the mainstem Green River at RM 40.7. Spawning escapement index data estimates for this stock from 1960 to 1996 is shown in Figure CSP-4, averaged 5,029 and ranged from 1,034 to 9,300.

The naturally spawning coho population in the Green River basin is comprised of an unknown mixture of natural and hatchery origin fish. The magnitude of adult hatchery fish that contribute to the natural spawning population has not been determined. The spawning escapement estimates in Figures CSP-3 and CSP-4 include hatchery strays, a fact that leads to overestimation of the "wild" coho run produced by naturally spawning parents. If large numbers of hatchery strays are included in SASSI escapement estimates, the SASSI status designation for this population could be changed to reflect that contribution.

Figure CSP-4: Newaukum Creek Coho Spawning Escapement Index Data 1960 - 1996.



GREEN/DUWAMISH RIVER BASIN CHUM SALMON POPULATION TRENDS

The chum salmon that enter the Green River basin are part of the South Puget Sound area chum stocks (Phelps et al. 1995). They are further separated into two stocks (WDFW and WWTIT 1994); Green River fall-run chum and Crisp Creek (also referred to as Keta Creek) fall-run chum salmon. The origin of Green River fall-run chum is an East Kitsap/wild remnant mix, while the Keta Creek fall-run stock is of East Kitsap (Cowling Creek broodstock whose origin is from Chico Creek) origin (Dorn 2000).

Chum salmon escapement for the Green River basin is sparse. Spawner survey data go back as far as 1947 where 452 chum were observed in Burns Creek. More recent surveys have shown significant numbers (nearly 700 adults in November 1987) of fish present but these fish were believed destined for the Keta Creek hatchery program. Spawning information on the remnant mixed origin Green/Duwamish River stock is limited and no attempt is made here to provide escapement estimates.

GREEN/DUWAMISH RIVER BASIN PINK SALMON POPULATION TRENDS

Williams (1975) characterized Green River pink salmon as extinct from this basin. Additionally, no mention of a pink salmon in the Green/Duwamish River basin stock was made in SASSI (WDFW and WWTIT 1994). More recently, Fuerstenberg (In Progress 1998) was unable to locate reports of pink salmon present in the Green River basin. Low numbers of pink salmon adults are observed in odd number years during spawning ground surveys in the mainstem Green River and a few tributaries (WDFW, 1999a). Additionally, personal observations by fisheries biologists in 1999 have confirmed the presence of pink salmon adults in low numbers in the mainstem Green River. Adults have been observed as far upstream as the confluence with Burns Creek (RM 41.5). In 2000, juvenile pink salmon were reported to have been captured in a screw trap on the mainstem Green River at RM 34.5. This is a clear indication of reproductive success at least through the spawning, incubation and hatching life history trajectories.

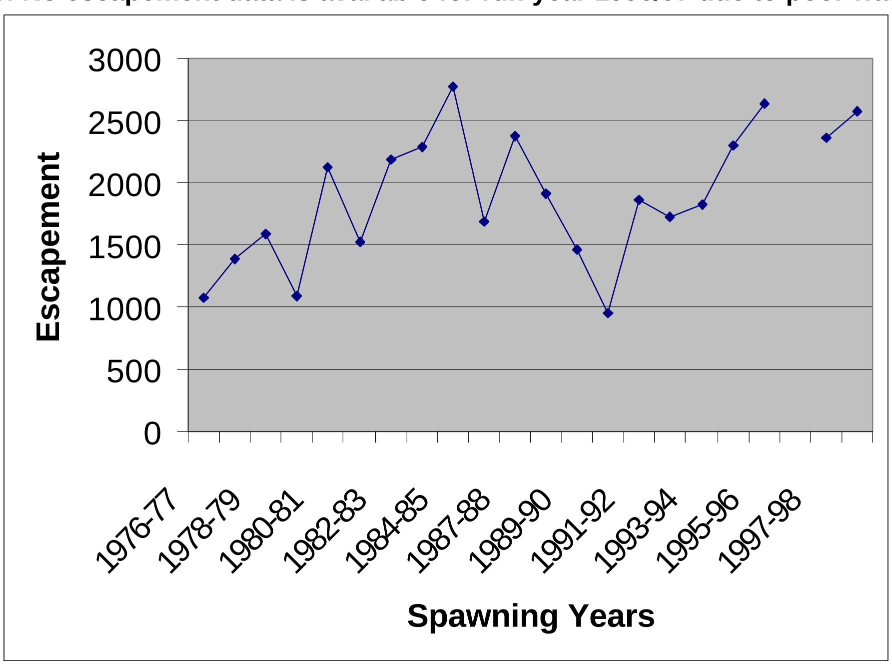
It is not clear if these are strays from other basins attempting to recolonize the Green River or remnant fish from the historic native population. Currently, the stock status for this species is unknown, but because of the low numbers present is believed to be depressed. Observations of spawning adults have been in odd number years only and the stock is believed to return in odd numbered years only.

GREEN/DUWAMISH RIVER BASIN WINTER STEELHEAD POPULATION TRENDS

There are two Green/Duwamish River basin winter steelhead stocks characterized in SASSI (WDFW and WWTIT 1994). These stocks are: the native wild spawning population and; the early timing hatchery stock. The status of both winter steelhead stocks has been characterized as healthy (WDFW and WWTIT 1994). Population trends of Green River wild winter steelhead in the early 1990's began a steady decrease similar to those of many other regional stream systems. Similar to many of those systems, Green River wild winter steelhead have rebounded. Recent (run year 1999-2000) escapement estimates were less than desired and are currently the cause of some concern.

No escapement data for Green/Duwamish River basin origin winter steelhead stocks is available prior to 1978. Escapement estimates are not available for 1997 due to poor water visibility conditions. Winter steelhead escapement to the Green/Duwamish River basin is depicted in Figure CSP-5.

Figure CSP-5: Green/Duwamish River Winter Steelhead Escapement Estimates Run Years 1977/8 – 1998/9. Note: No escapement data is available for run year 1996/97 due to poor water visibility.



GREEN/DUWAMISH RIVER BASIN SUMMER STEELHEAD POPULATION TRENDS

There may have been a historic native wild summer steelhead stock in the Green River Basin. Prior to 1966, sport angler punch cards indicated an annual summer steelhead harvest of small numbers (<12) fish per year (1962-66). SaSI (WDFW and WWTIT 1994) concluded that adult summer steelhead caught in the Green River basin were the result of strays from other systems or the result of adult winter steelhead caught during the summer steelhead management period (May 1 to October 31). The Green River Basin is within the geographic range of summer steelhead, approaching the northern edge and it is possible that it may have had a small historic summer steelhead population.

The current summer steelhead in the Green River Basin are the result of non-native (hatchery introduced) origin fish from the Skamania summer steelhead stock initially introduced in 1965. Escapement goals are not set for this stock as it is thought to be almost entirely hatchery supported and managed for the recreational sport fishery.

GREEN RIVER BULL TROUT POPULATION TRENDS

The stock status for bull trout in the basin is unknown (WDFW 1998). Information on the presence, abundance, distribution, utilization and life history of bull trout in the Green River basin is either unavailable or extremely limited. Suckey first observed native char in the Duwamish River during June 1856. He observed specimens as large as two feet in length in the Duwamish and another individual fish was captured approximately 35 miles upstream in June 1856 (Suckey and Cooper 1860). These fish were described as “red-spotted salmon trout” with the scientific name of *Salmo spectablis*. Pautzke and Megis (1940) described the presence of a “few” Dolly Varden during the 1930’s in the Green River. More recently, Mongillo (1993) suggested the need for additional data collections. Investigations (Watson and Toth 1994, Tacoma Water HCP 1999 Draft) have not provided any evidence of bull trout spawning in the Green River Basin. However, native char have been captured as far as RM 40 in the Green River (Watson and Toth 1994). Recreational anglers have reported sightings of native char in the lower Green River (H. Boynton, pers. comm.). Native char have not been observed or captured upstream of Howard Hanson Dam as a part of surveys conducted by Plum Creek Timber Company (Watson and Toth, 1994).

Bull trout are reported to have been recovered in the lower mainstem Green/Duwamish River on several occasions. A single bull trout was reported captured at the Soos Creek Hatchery rack in 1956 (Beak 1996). There is no supporting data regarding this reported individual fish. That paper attributed this information to a personnel communication from Fred Goetz (1994). During a fish study conducted by the Port of Seattle, a single adult Dolly Varden was reported captured in the Duwamish River at RM 2.1 (Weitkamp 1980). In 1980 one bull trout/Dolly Varden was collected, downstream of RM 4.0, as part of a juvenile salmonid study in the Duwamish River (Weitkamp 1982). No meristic sampling was conducted on these three fish so it is unclear if they are bull trout or Dolly Varden.

An adult bull trout was captured by the Muckleshoot Indian Tribal staff at approximately RM 5 during juvenile beach seining sampling efforts in 1994 (R. Malcom 1999). This later fish was analyzed by the University of Washington and confirmed to be a bull trout. It is uncertain if these fish were of Green/Duwamish River basin origin, were of non-Green/Duwamish River basin fish temporarily rearing in the Green/Duwamish River basin, or were strays attempting to recolonize the basin.

GREEN RIVER COASTAL CUTTHROAT TROUT STOCK COMPLEX POPULATION TRENDS

Coastal cutthroat trout (*O. clarki clarki*) are a subspecies of cutthroat trout (*O. clarki*) that are believed to have diverged into separate lines about 1 million years ago (Behnke 1997). Currently, WDFW uses the concept of a "Stock Complex" to identify coastal cutthroat stocks. The definition of a Stock Complex is: A group of stocks typically located within a single watershed or other relatively limited geographic area believed to be closely related to one another. This concept was developed in response to genetic analyses conducted by a number of investigators that showed there is a high degree of genetic diversity among coastal cutthroat trout populations even within small stream systems.

SaSI (WDFW 2000) identified a distinct stock of coastal cutthroat trout in the Green River Basin. This unique identification was based on geographic distribution and recognized a lack of data to attain certainty for this conclusion (WDFW 2000). The NMFS ESU for coastal cutthroat trout includes the Green River Basin (Johnson et al 1999). In the NMFS coastal cutthroat status review (Johnson et al 1999) indicated that few data was available concerning historic and present abundance of coastal cutthroat trout in the ESU.

Assessing populations of coastal cutthroat trout in the Green River Basin is particularly difficult. A reduction in habitat capacity within the Puget Sound ecoregion has been widespread as streams were extensively modified beginning in the late 1800's and continuing through today. Data for trends in coastal cutthroat trout abundance in Green River Basin streams is not available at the time of this report. Data from other Puget Sound river systems is mixed and often times coastal cutthroat trout are caught incidentally, in river traps, to a targeted species such as coho.

NMFS found that the scarcity of information available made risk assessments extremely difficult for coastal cutthroat trout. In their final conclusion(Johnson 1999), they determined that there were two alternative conclusions:

- "There is not enough evidence to demonstrate that coastal cutthroat trout are *not* at a significant risk of extinction; and
- "There is not enough evidence to demonstrate that coastal cutthroat trout are *not* at risk."

In SaSI (WDFW 2000), it was the conclusion of the editors that the stock status of Green River Complex coastal cutthroat was unknown. The only data they cited was limited electrofishing surveys conducted in Newaukum Creek.

SALMONID DISTRIBUTION

The current known freshwater distribution of anadromous salmonids within the Green/Duwamish River basin and independent tributaries to Puget Sound in WRIA 9 is illustrated in the Fish Distribution Maps located in the Appendix. Information for the known distribution was obtained from tribal, state, county and federal fishery professionals and published databases (SASSI, WDFW Spawning Ground Survey Database, and StreamNet, etc.).

The current known freshwater distribution potentially underestimates the actual distribution of salmonids because it does not include the presumed distribution. The presumed distribution of salmonids is being addressed through efforts by the Northwest Indian Fish Commission, Salmon and Steelhead Habitat Inventory Project (SSHIAP). In many cases the smaller tributaries have not been surveyed. Often times, private landowners deny survey crews access to creeks. Some reaches of streams and rivers are not surveyed due to difficult access caused by natural terrain. Stream gradient break points are being established and a presumed distribution map should be available later in 2000.

LIST OF TABLES AND FIGURES

Table HSP 1: Numbers of chinook, coho and steelhead females spawned at the Green River Eyeing Station 1911 – 1920

Table HSP 2: Escapement estimates of coho chinook and steelhead upstream of Tacoma Head-works project prior to project construction

Table HSP3: Escapement estimates for spring chinook, coho and winter steelhead to Upper Green River subbasin pre-1911

Table HSP 4: Estimated chinook, coho and winter steelhead smolts produced and adult returns under pristine conditions for the upper Green River subbasin

Table HSP 5: A comparison of predicted escapement estimates and returns of adult chinook, coho and steelhead from three historical perspectives for the Green River upstream of the Tacoma Headworks project.

Table HSP 6: Historic sport catches of summer-run steelhead in the Green River 1962-1982

Table CSP-1. Salmon species and stocks found in the Green/Duwamish River.

Figure CSP-1. Escapement for the Green/Duwamish River summer/fall chinook stock from 1986 to 1997.

Figure CSP-2. Newaukum Creek (WRIA 9) Summer/Fall Chinook Escapement 1987 - 1997.

Figure CSP-3. Green/Duwamish River (WRIA 9) Coho Escapement 1967 - 1998.

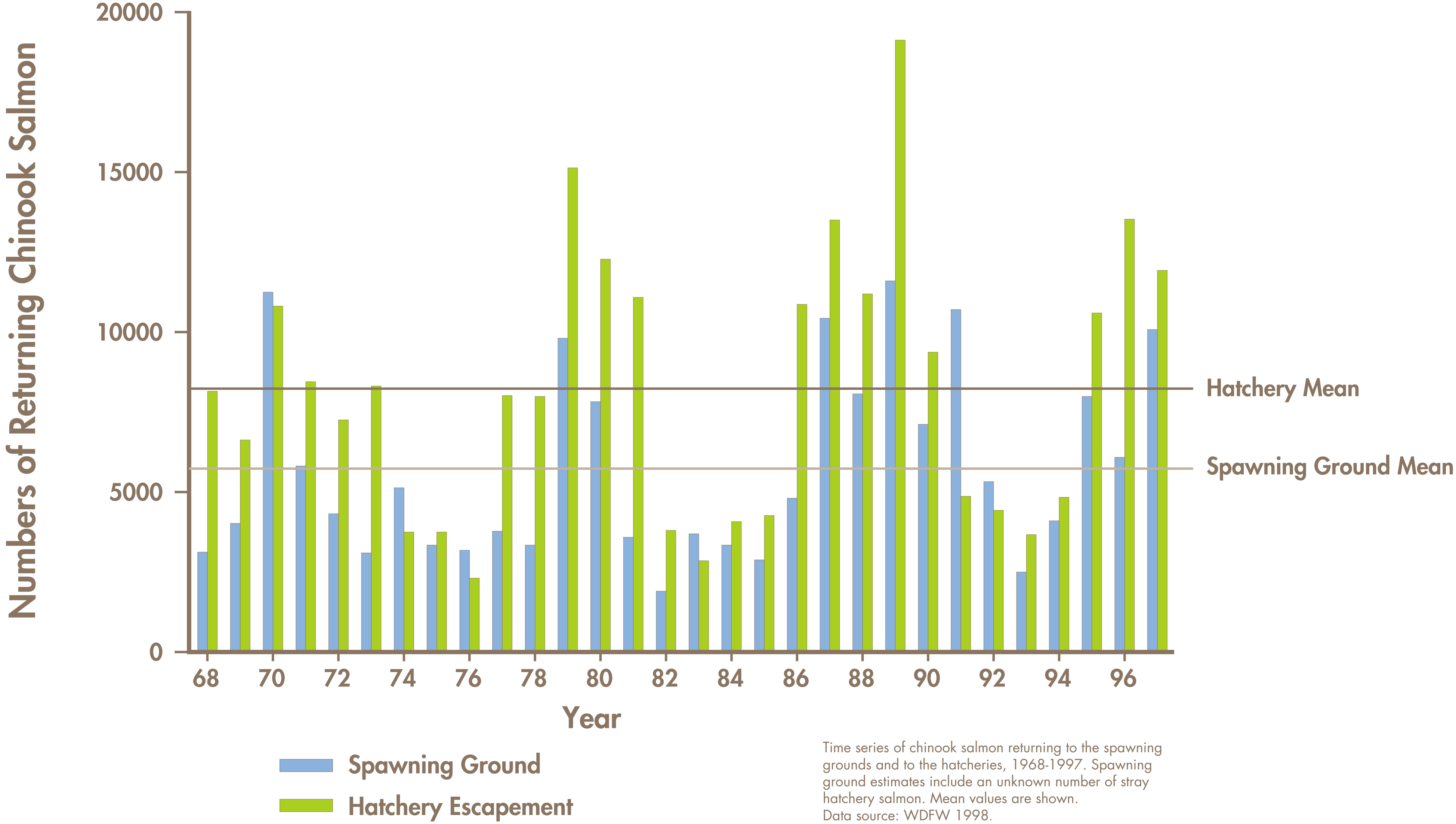
Figure CSP-4. Newaukum Creek Coho Spawning Escapement Index Data 1960 - 1996.

Figure CSP-5. Green/Duwamish River Winter Steelhead Escapement Estimates Run Years.

Figure CSP-6. Returning Chinook Salmon to the spawning grounds and hatcheries 1968-1997.

Figure CPS-7. Green/Duwamish River Chinook First Year Rearing Patterns.

Figure CPS-8. Green River Wild Chinook Salmon—annual total run, harvest and escapement of Green River “wild” chinook salmon.



Time series of chinook salmon returning to the spawning grounds and to the hatcheries, 1968-1997. Spawning ground estimates include an unknown number of stray hatchery salmon. Mean values are shown.
Data source: WDFW 1998.

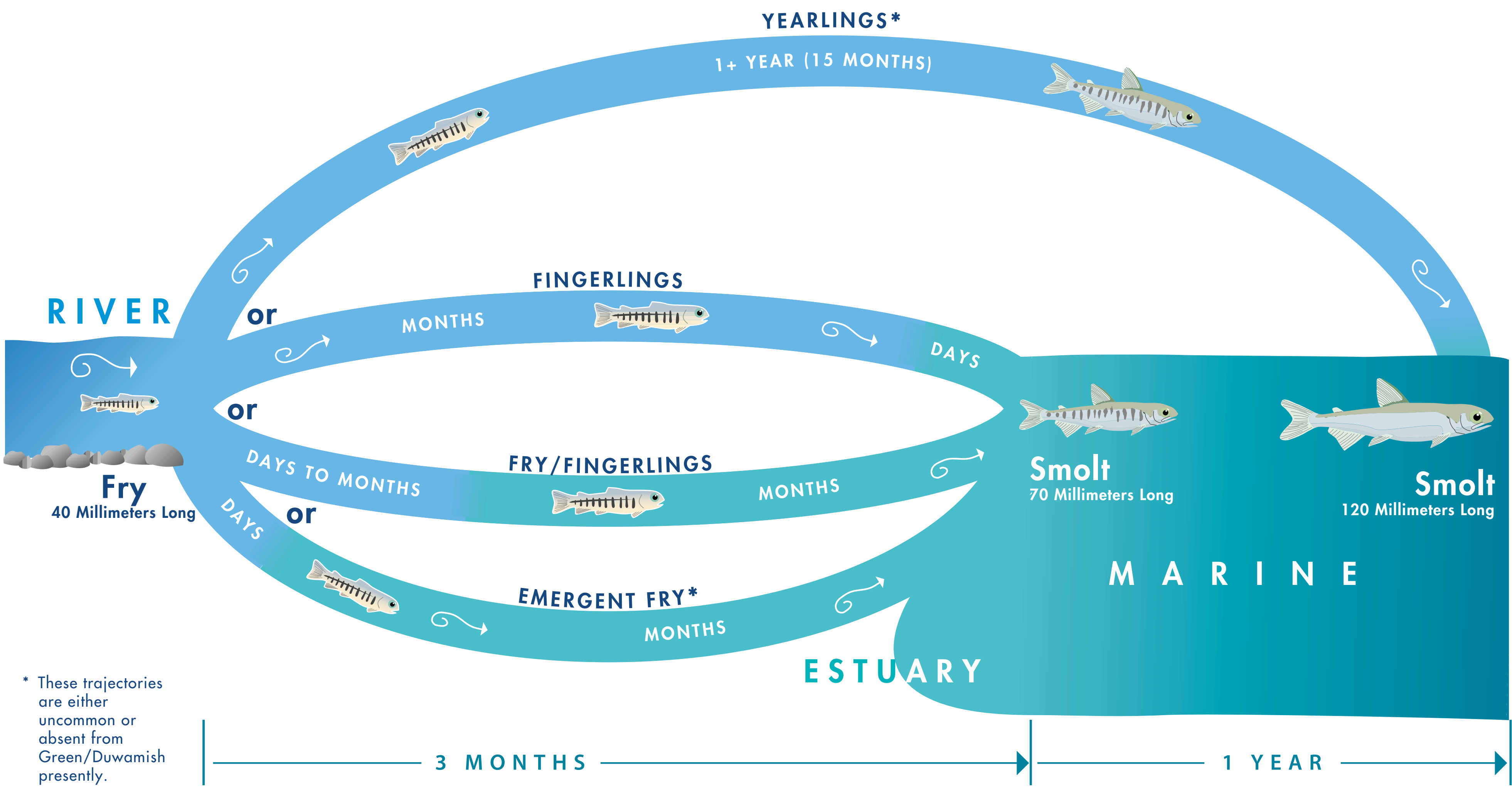
Figure CSP-6

Returning Chinook Salmon to the Spawning Grounds and Hatcheries 1968-1997

WRIA 9

King County
Department of Natural Resources

Map produced by: GIS & Visual Communications Unit, WLR
File Name: 0012 W9 ReturningChinook.ai

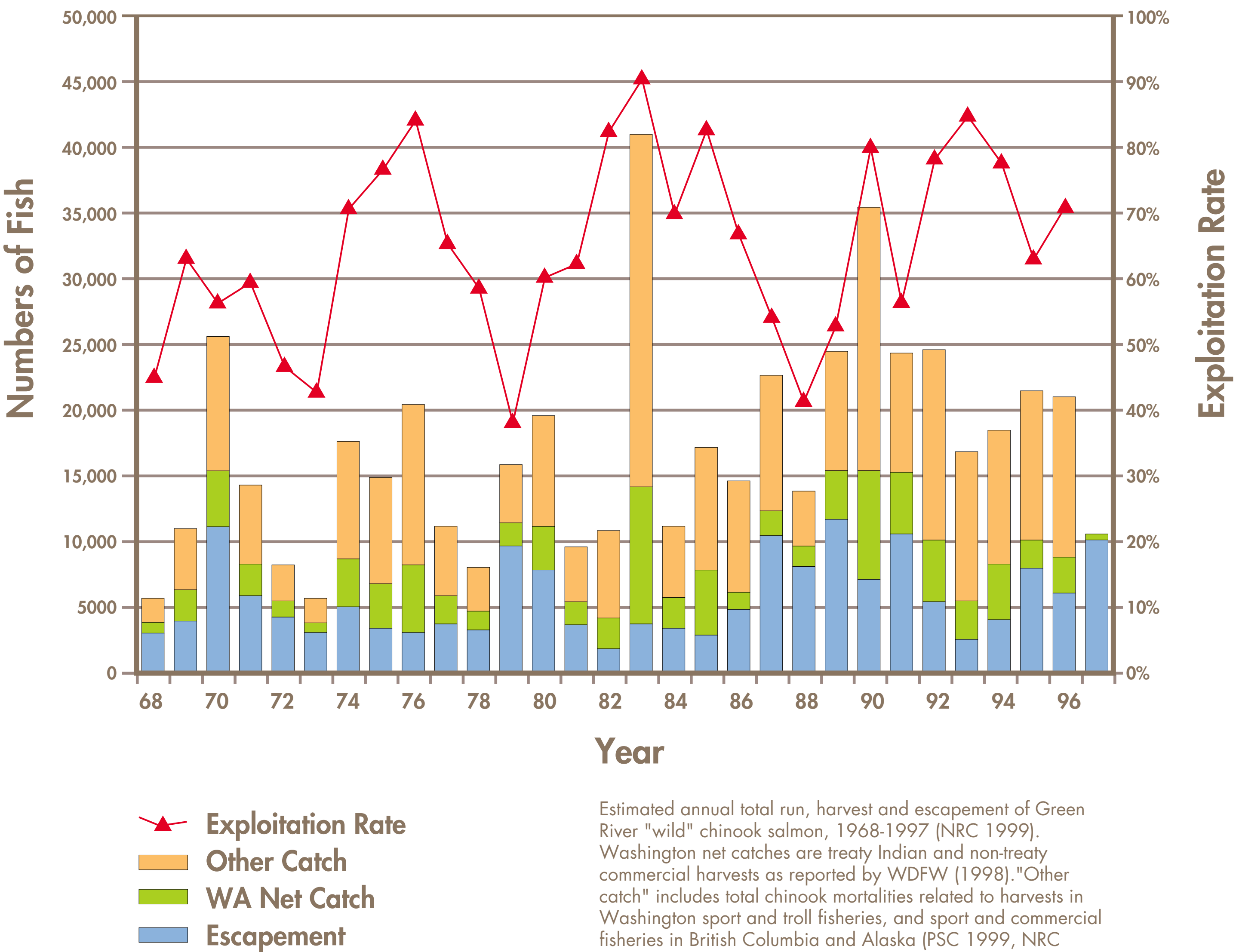


* These trajectories are either uncommon or absent from Green/Duwamish presently.

Figure CSP-7

Green/Duwamish River Chinook First Year Rearing Patterns

Poster produced by:
King County DNR
GIS & Visual Communications Unit
0012 W9 ChinookRear.ai WG,lp



Estimated annual total run, harvest and escapement of Green River "wild" chinook salmon, 1968-1997 (NRC 1999). Washington net catches are treaty Indian and non-treaty commercial harvests as reported by WDFW (1998)."Other catch" includes total chinook mortalities related to harvests in Washington sport and troll fisheries, and sport and commercial fisheries in British Columbia and Alaska (PSC 1999, NRC 1999). Total mortality estimates include estimated mortality of fish released after capture in fisheries (e.g., chinook non-retention fisheries and sublegal-sized fish, PSC 1999). "Wild" chinook estimates include hatchery fish that stray onto spawning ground. "Other catch" estimates were not available in 1997.

Figure CSP-8

Green River Wild Chinook Salmon

Annual Total Run, Harvest and Escapement of Green River "Wild" Chinook Salmon

King County
Department of Natural Resources

Map produced by: GIS & Visual Communications Unit, WLR
File Name: 0012 W9 Chinook Graph.ai

PART I: INTRODUCTION

4. Salmon Genetics

4. SALMON GENETICS

EXECUTIVE SUMMARY

The genetic diversity of a salmon species is important to that species abilities to undergo and withstand changes in climate, natural predation, diseases, competition, ocean rearing conditions and natural catastrophes. It is through this resiliency that the species survive.

The National Marine Fisheries Service has provided guidance in the form of three components of a successful restoration strategy (NMFS 1996). Such a strategy should consist of the following elements: (A) *protection* and *conservation*; (B) *certainty* that the strategy will be implemented and (C) a *comprehensive monitoring program.* NMFS expanded that guidance into three additional fundamental elements ultimately need to be addressed. Those include: (1) "…increased abundance of naturally spawned fish…"; (2) a "…broad geographic distribution of naturally spawned fish…"; and (3) a "…genetic diversity in a pattern and at levels consistent with natural evolutionary processes...". In this document we intend to supply the reader with the information necessary to assist in answering the third element.

There have been several attempts to organize salmon populations along genetic lines. Currently, the National Marine Fisheries Service (NMFS) has organized salmon populations in Evolutionary Significant Units (ESUs). An ESU is best defined as a population (or group of populations) that is (1) reproductively isolated from other conspecific population units (separate from), and (2) represents an important component in the evolutionary legacy of the species (unique). The isolation of a population does not have to be absolute, but strong enough to allow for evolutionary important differences to accrue between populations. The second criteria is best met if the population contributes to the ecological and/or genetic diversity of the species as a whole. (Waples 1991). The boundaries of Puget Sound salmonid ESUs often overlap but differ between species.

Much of the genetic data used to define ESUs has come from information obtained by the Washington Department of Fish and Wildlife (WDFW) and the Western Washington Treaty Indian Tribes (WWTIT). WDFW has organized stocks into genetic diversity units (GDUs) and major ancestral lineages (MALs). In most cases, GDUs are grouped into larger assemblages called Major Ancestral Lineages (Marshall et al. 1995). The GDU/MAL initiative was intended as part of an effort to provide NMFS with pertinent information to assist in ESU designations. Given that much of the genetic data used in the federal ESU determinations were collected and analyzed on behalf of the State of Washington (Marshall et al. 1995), it is not surprising that the Puget Sound chinook MAL contains a group of populations similar to the ESU grouping. This is not always the case with other salmon species as the ESUs and MALs often overlap but have different boundaries.

A summary of stock status, stock history and ESA status is contained in table Gen-1.

Green River origin fall chinook have the largest amount of genetic information available, followed by chum and coho salmon. Steelhead have undergone a similar level of scrutiny but utilizing different investigative techniques. Sockeye salmon populations in the Green River have not been genetically evaluated. Pink salmon are known to occur in the Green River but are not considered viable by the natural resource management agencies and are not discussed in this document.

Table Gen-1. Salmon Species and Stocks Found in the Green/Duwamish River (WDFW and WWTT 1994). The NMFS Evolutionary Significant Units (ESU) and listed or proposed Endangered Species Act (ESA) listing status are also shown as of October 4, 1999.

Stock [1]	Stock Origin [2]	Production Type [3]	ESU	ESA Status
Duwamish/Green River Fall Chinook	Mixed [4]	Composite [7]	Puget Sound [10]	Threatened
Newaukum Creek Fall Chinook	Mixed	Wild [8]	Puget Sound [10]	Threatened
Duwamish/Green River Fall Chum	Mixed	Composite	Puget Sound /Strait of Georgia [11]	Not Warranted
Crisp (Keta) Creek Fall Chum	Non-native [5]	Cultured [9]	Puget Sound /Strait of Georgia [11]	Not Warranted
Green River/Soos Creek Coho	Mixed	Composite	Puget Sound/Strait of Georgia [12]	Candidate
Newaukum Creek Coho	Mixed	Composite	Puget Sound/Strait of Georgia [12]	Candidate
Duwamish/Green River Summer Steelhead	Non-native	Composite	Puget Sound [13]	Not Warranted
Duwamish/Green River Winter Steelhead	Native [6]	Wild	Puget Sound [13]	Not Warranted
Duwamish/Green River Early Winter Steelhead (Chambers Ck.)	Non-native	Cultured	Puget Sound [13]	Not Warranted
Green River Sockeye [14]	Unknown	Wild	Not Determined	Uncertain
Green River Bull Trout [15]	Native	Wild	Puget Sound	Proposed Threatened
Green River Coastal Cutthroat Trout [16]	Native	Wild	Puget Sound	Not Warranted

Notes
1. As defined in WDFW and WWTT (1994), the fish spawning in a particular lake or stream(s) at a particular season, which fish to a substantial degree do not interbreed with any group spawning in a different place, or in the same place at a different season.
2. The genetic history of the stock
3. The method of spawning and rearing that produced the fish that constitutes the stock.
4. A stock whose individuals originated from commingled native and non-native parents, and/or by mating between native and non-native fish (hybridization) or a previously native stock that has undergone substantial genetic alteration.
5. A stock that has become established outside of its original range.
6. An indigenous stock of fish that have not been substantially impacted by genetic interactions with non-native stocks, or by other factors, and is still present in all or part of its original range.
7. A stock sustained by both wild and artificial production
8. A stock that is sustained by natural spawning and rearing in the natural habitat, regardless of parentage (includes native)
9. A stock that depends on spawning, incubation, hatching, or rearing in a hatchery or other artificial production facility.
10. Meyers *et al.* (1998).
11. Johnson *et al.* (1997).
12. Weitkkamp *et al.* (1995).
13. Busby *et al.* (1996).
14. Not listed in WDFW and WWTT (1994)
15. Listed in WDFW SaSI (1998).
16. Johnson et al (1999).

KEY FINDINGS AND DATA GAPS

FALL CHINOOK HIGHLIGHTS

- The Green River has had a fall chinook hatchery program for the last 95 years.
- Green River fall chinook have played an important part in a number of hatchery programs throughout Puget Sound.
- Green River hatchery and Newaukum wild fall chinook populations are genetically indistinguishable.
- Draft data indicates that the contribution of natural spawned adults to escapement at the Soos Creek Hatchery is approximately 39 percent (range: 1 to 76 percent).
- Draft data indicates that the contribution of natural spawned adults to escapement in the Newaukum River is approximately 45 percent (range: 15 to 79 percent).
- Draft data indicates that the contribution of natural spawned adults to escapement in the Green River is approximately 56 percent (range: 25 to 83 percent).

FALL CHINOOK DATA GAPS

- The exact contribution of hatchery fall chinook to mainstem Green River natural escapement is not yet fully known.
- In the Green River Basin, the ramifications genetic flow between the hatchery and wild populations is unknown.

CHUM HIGHLIGHTS

- The Green River has had a chum hatchery program since 1976.
- Green River chum salmon are geographically isolated from other chum salmon populations in Puget Sound.
- Two chum salmon stocks exist within the Green River Basin.

CHUM DATA GAPS

- The extent of chum salmon straying in the Green River Basin is unknown.
- In the Green River Basin, the ramifications genetic flow between the hatchery and wild populations is unknown.

COHO HIGHLIGHTS

- Green River hatchery and Newaukum coho are genetically similar.
- Green River Basin coho are listed as a Candidate for listing under the ESA.

COHO DATA GAPS

- The contribution of hatchery coho to natural escapement is unknown. The reverse is also true.
- In the Green River Basin, the ramifications genetic flow between the hatchery and wild populations is unknown.
- The actual extent of any temporal separation in timing between Green River and Newaukum Creek coho is unclear in terms of defining separate stocks.

WINTER STEELHEAD HIGHLIGHTS

- Green River origin winter steelhead are a part of the larger wild Puget Sound winter-run steelhead stocks.

WINTER STEELHEAD DATA GAPS

- In the Green River Basin, the ramifications genetic flow between the winter steelhead hatchery and wild populations is unknown.
- Because of timing differences the genetic flow between these stocks is believed to be low.

INTRODUCTION

As human populations have increased in the Green River Basin, tremendous pressure has been put on salmon and steelhead stocks. Demand for these fish has increased as their habitat base has been reduced. Several years of unfavorable marine conditions have reduced their survival. Management planning has considered issues such as harvest, reduced marine survival and freshwater productivity, but until recently has not considered the magnitude and importance of the genetic diversity of these fish.

The knowledge of the genetic stock structure of salmon and steelhead is now recognized as a fundamental issue for their conservation and management. These fish exhibit a tremendous amount of genetic diversity that is revealed through ecological, life history and molecular genetic variability. The genetic diversity that these fish contain is a major contributor to current productivity and, potentially more important, a resource for adaptive change. It is the genetic diversity available for adaptive change that will promote future productivity and survival.

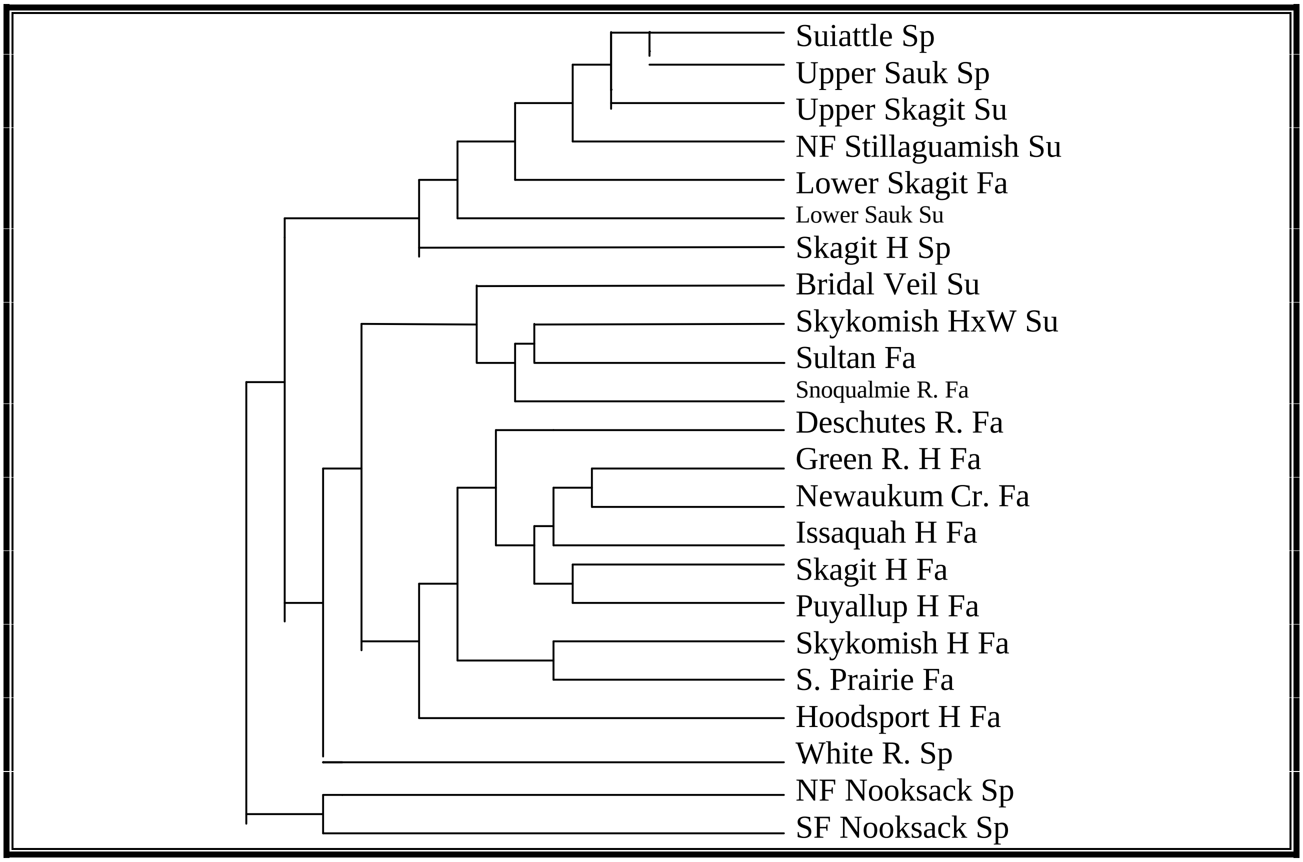
To understand and conserve genetic diversity it is important to understand the existing amount and pattern of genetic diversity. This paper is an attempt to provide the reader with an overview of current genetic issues of Green River Basin salmon and steelhead. Scientists are still investigating the genetics of Green River salmon and steelhead stocks, as well as others within the region. It is possible; that as new information becomes available the views presented below may change.

BACKGROUND

In this paper we present the reader with biochemical and molecular genetic evidence that has been used to define reproductively isolated populations of Green River origin chinook, chum and coho salmon, along with winter steelhead. The methods by which much of this data is processed is very technical, the details of which are not necessary for the purposes of the information presented below. However, it is useful to know that the bulk of the data consists of frequencies of protein variants (allozymes) or mitochondrial DNA identified through electrophoresis. After the allozymes are identified, several standard statistical methods are used to analyze the molecular genetic data in order to test various hypothesis of reproductive isolation. These methods are applied within and between populations. A finding of significant frequency differences between populations may be evidence of reproductive isolation.

There are additional methods of measuring the genetic isolation between populations. These methods calculate genetic differences from allele-frequency estimates and may use one or more of several genetic distance measures. It is unclear if one method is always superior to the others as each method has its own inherent strengths and weaknesses. There are several technical papers available that discuss the different approaches (Nei 1978; Hillis et al 1996; and Rogers 1991). A method commonly employed is to place genetic data from stocks on a chart, called a dendogram, which resembles a branching family tree. This method of viewing genetic data suggests similarities and differences between groups or samples. A typical dendogram can be found in Figure Gen-1.

Figure Gen-1. Dendogram Resulting from Cluster Analysis among Puget Sound Chinook Populations (Source: Marshall 1995).



H = Hatchery W = Wild Sp = Spring-run Su = Summer-run Fa = Fall-run

NATIONAL MARINE FISHERIES SERVICE

The Endangered Species Act allows the listing of "distinct population segments". The National Marine Fisheries Service (NMFS) has developed a policy on this issue for anadromous Pacific salmonids that considers a population distinct if it represents an Evolutionary Significant Unit (ESU). An ESU is defined as a population (or group of populations) that is reproductively isolated from other conspecific population units, and (2) represents an important component in the evolutionary legacy of the species. Definitions for the terms "Threatened," "Endangered," "Candidate," and "Not Warranted for Listing" are contained in the Glossary.

NMFS has used data collected by others as well as NMFS geneticists in an effort to analyze the biochemical and molecular genetic evidence that might be used to define reproductively isolated populations of salmonids. Through this analysis coupled with data on life-history differences they have identified distinct population segments.

ESU STATUS

Puget Sound chinook were listed as a threatened species on March 24, 1999. The ESU included Green River origin naturally spawned populations. Chinook salmon from the Green River Hatchery were not included in the listing. The Puget Sound steelhead, chum and odd year pink salmon ESUs were determined to "Not Warrant" listing as threatened or endangered. Puget Sound coho have been listed as a candidate species that warrants further consideration. The Green River is not part of a sockeye salmon ESU. Actual ESU boundaries vary by species and the details of those ESU boundaries can be found below.

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

In 1985, the Washington Department of Fish and Wildlife (WDFW) began actively characterizing the genetic diversity among salmonid stocks in Washington state (Busack 1995). Through the use of collected genetic data, coupled with life history traits, ecological and physiological data, these stocks were initially described as Genetic Conservation Management Units GCMUs by Leider et al. (1994). The development of GCMUs was meant to parallel the NMFS Evolutionary Significant Units (ESUs) and the Washington Department of Wildlife (WDW) Draft Steelhead Management Plan.

Also in 1994, WDFW undertook an effort to systematically summarize and analyze the data produced by previous efforts to document the genetic diversity of salmonid species. Through the development of the WDFW Wild Salmonid Policy (WSP) and the 1994 effort to further analyze previously collected data new terminology evolved. This data led to organizing stocks of salmon into assemblages of biologically and genetically similar groups called Genetic Diversity Units (GDUs). In most cases, GDUs are grouped into larger assemblages called Major Ancestral Lineages (MALs) (Marshall et al. 1995). Given that much of the genetic data used in the federal ESU determination were collected and analyzed on behalf of the State of Washington (Marshall et al. 1995), it is not surprising that the Puget Sound chinook MAL contains a group of populations similar to the ESU grouping. The Puget Sound chinook ESU, as defined by NMFS (Myers et al. 1998), includes all of the Puget Sound GDU's, but also includes populations in Strait of Juan de Fuca streams from the Elwha River east. The Strait of Juan de Fuca is a migratory corridor for Puget Sound chinook, and appears to be a natural transition zone between coastal and interior chinook populations.

A Genetic Diversity Unit (GDU) is defined as: "A group of genetically similar stocks that is genetically distinct from other such groups. The stocks typically exhibit similar life histories and occupy ecologically, geographically and geologically similar habitats. A GDU may consist of a single stock" (Busack 1995).

GDUs are subdivisions of MALs and a MAL may be comprised of several GDUs. Stocks within a GDU may be genetically similar, but are not identical. Within a GDU there may be measurable genetic differences and low levels of natural gene flow among stocks. The reader is cautioned that GDU designations are only an initial attempt to group current patterns of diversity seen in these species and additional analyses may change both the groupings and terminology. Finally, these GDU designations are a picture of what we know today and may not be representative of what these fish looked like 150 years ago or may look like 150 years into the future.

While a GDU is based on similarities and differences currently exhibited by these fish, a Major Ancestral Lineage (MAL is based on groups that are so different genetically that they are reflective substantial reproductive isolation over extended periods of time. Busack (1995) defined a MAL as: "A group of one or more genetic diversity units (GDUs) whose shared genetic characteristics suggest a distant common ancestry, and substantial reproductive isolation from other MALs. Some of these groups are likely the result of colonization and diversification preceding the last period of glaciation."

GREEN RIVER FALL CHINOOK SALMON GENETICS

NATIONAL MARINE FISHERIES SERVICE

NMFS (Meyers 1998) determined that there are fifteen ESUs of chinook salmon in California, Oregon, Washington and Idaho. Based in part on genetic evidence presented in Marshall et al. (1995), the NMFS has drawn the boundaries of the Puget Sound Chinook ESU.

The Puget Sound ESU extends from the Nooksack River in the north through Puget Sound and west into the Strait of Juan de Fuca to Elwha River. The Elwha River chinook stocks are somewhat intermediate between Puget Sound and Coastal ESU but their marine distribution more closely matches that of Puget Sound stocks. Spring-, summer- and fall-run chinook wild and some hatchery stocks are included in this ESU. The proposed Puget Sound ESU for chinook salmon is similar in geographic coverage to ESUs for steelhead but differs from that proposed for chum, coho and odd-year pink salmon.

The naturally spawning component of the Green River chinook run contains a mixture of wild and hatchery chinook. The major question pertaining to the status of Green River chinook is the contribution of hatchery chinook to the natural escapement. Draft run-reconstruction information for the years 1989 – 1997 inclusive indicates approximately 56 percent (range: 25 to 83 percent) of the natural escapement in the mainstem Green River of being from hatchery reared and released fish (Cross, pers. comm.1999). It is not possible to determine to what extent the remaining approximate 40 percent of the mainstem Green River escapement has its ancestry from hatchery origin fish that have spawned for one or more generations in the wild. For the same time period, in Newaukum Creek, the origin of adult chinook is approximately 45 percent (range: 15 to 79 percent) of hatchery origin (Cross, pers. comm.1999).. Additionally, draft data, for the same time period, indicates approximately 39 percent (range: 1 to 76 percent) of the adult chinook returning to the hatchery rack are progeny of natural spawning adults. Newaukum and Soos Creek data is probably quite reliable since sampling rates are relatively high (30 percent and 98 percent respectively) (Cross, pers. comm.1999). The Green River mainstem sampling rate was roughly 4 percent due to difficulties in locating samples in the large river and is probably less reliable. Sampling efforts in the mainstem Green River were increased beginning in 1998 but the data has not yet been analyzed. Additional details surrounding this issue were addressed previously in Chapter 4.

The Green River chinook salmon belong to a group of Puget Sound spawning populations that are genetically distinguishable from other chinook populations outside the region (Utter et al. 1989). In two subsequent studies (Marshall et al. 1995, Myers et al. 1998), the chinook populations of Puget Sound were also identified as being more similar to one another than to populations outside the region, based on comparisons of genetic characters. Among chinook outside the Puget Sound region, populations in southern British Columbia, Canada are genetically most closely related. The exact geographic boundaries of Puget Sound chinook, as drawn on the basis of genetic evidence, differ somewhat among sources. Based in part on genetic evidence presented in Utter et al. (1989) and in Marshall et al. (1995), NMFS has drawn the boundaries of the Puget Sound Chinook ESU at the eastern Strait of Juan de Fuca, including the Elwha River, to the Canadian border, including the Nooksack River (Myers et al. 1998). It should be noted that genetic data for naturally spawning Green River chinook was lacking from the federal analyses, which included Green River (Soos Creek) hatchery stock data collected between 1981 and 1990. A genetic baseline on Green River natural spawners from Newaukum Creek is available (Marshall et al. 1995).). Genetic data from chinook in Newaukum Creek indicates that there is no significant difference between chinook spawning naturally in Newaukum Creek and chinook from the Soos Creek Hatchery Rack (Marshall 1995).

Green River natural chinook are included in the Puget Sound ESU.

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

In addition to the ESU, the Green River chinook stock also appears in another system of salmon stock classification based largely on genetic data. WDFW has organized chinook into geographic assemblages of genetically similar groups known as Genetic Diversity Units (GDU's). The Puget Sound chinook ESU, as defined by NMFS (Myers et al. 1998), includes all of the Puget Sound GDU's, but it also includes the Strait of Juan de Fuca streams from the Elwha River east. The Strait of Juan de Fuca, which serves as a migratory conduit between these two geographic regions, is a natural zone of transition between coastal ocean and interior Puget Sound chinook populations.

Puget Sound has five GDUs encompassing wild and hatchery populations:

- South Puget Sound, Hood Canal and Snohomish Summer + Fall, (fall chinook in the Skagit, Nooksack and Samish hatcheries are included) chinook;
- South Puget Sound Spring (White River) chinook;
- Stillaguamish and Skagit (Skagit wild spring, summer, fall and hatchery springs; and all Stillaguamish) chinook;
- South Fork Nooksack Spring chinook; and
- North Fork Nooksack Spring chinook.

Green River chinook are included in the first of these GDU's, and transfers of Green River stock to other watersheds have helped to determine the geographic localities of this GDU.

NATURAL GREEN RIVER CHINOOK IN RELATION TO OTHER CHINOOK STOCKS

The Green River fall chinook reside at the geographic center of their ESU/MAL, and they are genetically very similar to a number of hatchery and naturally spawning stocks distributed throughout Puget Sound. For example, natural spawning populations genetically closely related to the Green River Hatchery chinook are found in the Skykomish River (summer), Bridal Veil Creek (summer), Wallace, Sultan and Snoqualmie rivers (fall), and South Prairie Creek in the

Puyallup River (fall) (Myers et al. 1998). However, these samples include hatchery strays and when those fish are removed from the sample, the Snohomish chinook (Sultan River, Snoqualmie River, and Bridal Veil Creek) stocks are significantly different (Smith pers. comm. 1999). Historically, Puget Sound hatchery stocks apparently derived from the Green River Hatchery stock were found at the Skagit Hatchery (summer and fall), Skykomish Hatchery (fall), the Deschutes Hatchery (fall), and the Hoodsport Hatchery (fall) based on the data presented in Meyers et al. (1998). Snohomish Hatchery fall chinook stocks were also founded with Green River Hatchery stock, however stocks of Green River Hatchery origin are no longer released from the Skagit and Snohomish hatcheries into their respective basins. In the WDFW studies, genetic baselines for the Green River natural and hatchery populations were closely related to Skykomish hatchery, Issaquah hatchery, Hood Canal hatchery, Puyallup natural and hatchery, and Deschutes hatchery (Marshall et al. 1995).

It is noteworthy that the Green River hatchery stock has played a role in the geographic distribution of the GDU's. The geographic boundaries of Puget Sound GDUs are overlapping. Populations in a GDU may be found in relatively diverse localities due, at least in some cases, to past and current transfers of fish among hatcheries. For example, the northern Puget Sound fall chinook in the Skagit, Nooksack and Samish hatcheries are part of the South Puget Sound, Hood Canal and Snohomish Summer and Fall chinook GDU due to the influence of Green River chinook (Marshall et al. 1995). Twenty hatcheries throughout Puget Sound regularly release Green River origin chinook, according to Marshall et al. (1995). As of 1998 operations, direct transfers of Green River hatchery chinook are more limited, as hatchery programs rely more on local stocks (Kimbel 1999).

It is also noteworthy that the reverse has not been the case. There have not been significant transfers of chinook stocks into the Green River from outside the ESU.

POSSIBLE CHANGES IN A GENETICALLY HERITABLE CHARACTER

The geographic boundaries of the ESU/MAL and the content of the GDU's were determined in part by analyzing a combination of heritable characters. Reproductive isolation is studied by using heritable characters not thought to be subject to natural selection, such as frequencies of neutral genes determined from analysis of tissue protein variants (allozymes), mitochondrial DNA and microsatellite loci (Myers et al. 1998). Differences in heritable physical characters subject to natural selection, such as size at age, timing of adult migrations and spawn timing, are less useful for identifying reproductive isolation. Nonetheless, changes in these heritable physical characters through time and within a population are useful indicators of changes in the genetic character of the population.

Data were available to study changes in timing of arrival at the Soos Creek hatchery rack for Green River chinook. Timing of rack returns was studied by testing annual mean date of rack return at Soos Creek hatchery for significant linear trend. A significant negative slope indicates the timing is probably getting earlier, and a significant positive slope indicates timing is probably becoming later. Mean date of annual rack returns from 1960 to 1997 varied from September 23 to October 13, with a grand mean of October 4. There was a small but statistically significant ($p < 0.05$) negative slope on the regression of mean date of annual rack return on year. The timing of rack returns of chinook to the Soos Creek hatchery rack became about one week earlier over a 38-year period. A limitation of this analysis is that the rack return data were summed on a weekly basis, so there is a measurement error of plus or minus one week. A change of a week or less could be due to measurement error, even though the time trend in date of rack return was statistically significant. These results indicate that an analysis of daily rack return data should be conducted, if these data can be found.

It is possible that timing of rack return for Soos Creek hatchery chinook has become earlier over the past 38 years. Annual mean dates of rack return later than October 4 are much less (three times) common in the past 10 years (1988 – 1997) than in the first 10 years (eight times) (1960 – 1969). This change coincides with changes in hatchery operational procedures that were initiated as a result of concerns expressed over genetic changes. One of the first guidance documents for WDWF hatchery genetics was published during the early 1980s (Hershberger and Iwamoto, undated). Spawning guidelines were provided to all Washington Department of Fisheries hatchery programs in 1983 (Seidel 1983). Both of these resulted in significant operational changes to hatchery spawning techniques that were intended to minimize any alteration to run timing. Additional factors such as water flow in Soos Creek, harvest patterns and changes in ocean rearing conditions could factor into this observation. However, should the differences in timing be real, this would indicate a change in the gene frequencies in the hatchery population over time.

GREEN RIVER CHUM SALMON GENETICS

NATIONAL MARINE FISHERIES SERVICE

Based in part on genetic evidence presented in Phelps et al (1995), the National Marine Fisheries Service (NMFS) has drawn the boundaries of the Puget Sound Chum Evolutionarily Significant Unit (ESU). NMFS (Johnson 1997) determined that there are two major genetic groups of chum salmon in central and southern British Columbia, Washington and Oregon. The smaller of these two groups consists of summer-run chum salmon in Hood Canal and the Strait of Juan de Fuca. The second, and much larger group, consists of fall-, winter- and summer-run chum salmon in other areas of British Columbia, Washington and Oregon. This last group was further divided into: 1) coastal populations along the outer coast of Washington and Oregon, and 2) the remaining populations in British Columbia and Washington. Green River fall-run chum salmon are in this last category.

The proposed Puget Sound/Strait of Georgia ESU for chum salmon is similar in geographic coverage to ESUs for coho and odd-year pink salmon but differs for chinook and steelhead.

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

The Washington Department of Fish and Wildlife (WDFW) places Green River chum salmon in a group of Puget Sound spawning populations that are genetically similar to other chum populations of central Puget Sound chum salmon (Phelps et al. 1995). The origin of portions of the Green River chum salmon is believed to be the result of transfers of Cowling Creek Tribal Hatchery (eastern Kitsap Peninsula) chum salmon (Phelps et al. 1995) into the Green River in an effort to establish chum runs in this system. This was one factor that influenced Phelps et al

(1995) to place Green River chum into the same Genetic Diversity Unit (GDU) with eastern Kitsap Peninsula chum.

One method by which chum salmon populations may be separated into GDU's is to examine differences in life histories. Life histories include geographic distribution of migration routes, timing of adult entry into freshwater, body size, coloration and time to maturation. Habitat differences include natal river origin (e.g., glacial vs. non-glacial), stream gradient, stream elevation and size of estuaries. Generally, these criteria can contribute to or reflect isolation between stocks or groups of stocks of salmon. Data has been collected on body size but they have not yet been analyzed for regional or stock differences.

The Puget Sound Region is separated into four major areas (Phelps et al. 1995):

- North Puget Sound (the Snohomish, Stillaguamish, Skagit and Nooksack rivers);
- South Puget Sound (the Puyallup and Nisqually rivers and independent tributaries of the southern Puget Sound inlets);
- Hood Canal (the Dosewallips, Duckabush and Hamma Hamma rivers); and
- Strait of Juan de Fuca (the Dungeness and Elwha rivers).

The chum salmon that enter the Green River are part of the South Puget Sound area (Phelps et al. 1995). They are further separated into two stocks (SASSI 1992); Green River fall-run chum and Crisp Creek (also referred to as Keta Creek) fall-run chum salmon. The origin of Green River fall-run chum is an East Kitsap/wild remnant mix, while the Keta Creek fall-run stock is of East Kitsap (Cowling Creek broodstock whose origin is from Chico Creek) origin (Dorn pers. comm. 1999).

Chum salmon spawning ground survey data from the Green River are limited. However, these data indicate that the Green River chum are fall spawners, spawn in mainstem side-channel and tributary habitats (SASSI 1992 and WDFW Spawning Ground Survey Database), share similar adult entry to freshwater timing and time of maturation to stocks on the eastern side of the Kitsap Peninsula. They are separated from chum found on the eastern side of the Kitsap Peninsula by the width of Puget Sound between Bainbridge Island and Elliot Bay. Because of the separation across Puget Sound, it seems unlikely that there is significant opportunity for substantial interchange of spawners. Chum salmon in South Puget Sound inlets exhibit straying between tributaries of an inlet but the exchange of spawners between inlets does not happen to the same degree (Phelps et al. 1995).

Another method by which chum salmon may be placed in GDU's is based largely on genetic data. WDFW (Phelps et al. 1995) has organized chum salmon into geographic assemblages of genetically similar groups known as GDU's.

Puget Sound has five chum salmon GDU's encompassing wild and hatchery populations (Phelps et al. 1995):

- North Puget Sound fall-run GDU;

- Nooksack, Skagit, Stillaguamish and Snohomish rivers and smaller independent tributaries flowing into major bays;
- Central/South Puget Sound summer-run GDU;
- Smaller independent tributaries to Puget Sound;
- Central/South Puget Sound fall-run GDU
- Duwamish/Green River, Puyallup/White (excluding Keta Creek) rivers and small independent tributaries to Puget Sound;
- South Puget Sound winter-run GDU;
- Nisqually River and independent tributaries in WRIA 11;
- Hood Canal fall-run GDU; and
- All Hood Canal streams.

While the available biological data indicates that Green River and central Puget Sound streams of the Kitsap Peninsula should be a distinct GDU, the genetic differences between these streams was small. Based on the genetic similarities, the Green River chum are included in the Central/South Puget Sound fall-run GDU.

GREEN RIVER COHO SALMON GENETICS

NATIONAL MARINE FISHERIES SERVICE

The National Marine Fisheries Service (NMFS) has drawn the boundaries of the Puget Sound Coho Evolutionarily Significant Unit (ESU) based in part on genetic data and on life history/ecological differences. NMFS (Weitkamp 1995) determined that there are six major genetic groups of coho salmon for the west coast of North America. The Puget Sound/Strait of Georgia ESU includes the drainages of Puget Sound, Hood Canal, the eastern Olympic Peninsula (east of Salt Creek) and portions of British Columbia. Green River coho salmon are in this ESU.

NMFS technical staff have collected allozyme data over a 10 year period from over 100 salmon samples to form the basis of Genetic Stock Identification (GSI) studies. Samples from the Green River Hatchery on Soos Creek were collected in 1982 and again in 1992. The analysis of this data yielded seven major "clusters" that were largely distinct geographically (Weitkamp 1995). One cluster included all coho populations of Puget Sound and British Columbia (except for two Fraser River samples and one sample from the Big Qualicum Hatchery).

The proposed Puget Sound/Strait of Georgia ESU for coho salmon is similar in geographic coverage to ESUs for chum and odd-year pink salmon but differs for chinook and steelhead.

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

The Washington Department of Fish and Wildlife (WDFW) has not scrutinized coho populations in Puget Sound to the same level as chinook or chum salmon. In the south and mid Puget Sound river systems, coho are generally managed for hatchery rather than natural production. The Green River receives substantial releases of hatchery origin coho annually. The release of yearling coho started in the 1950's and continues today. Regular releases of fingerlings occurred from 1952 to 1962 and from the mid 1970's until 1997. Releases of juvenile coho occur onsite at the Soos Creek Hatchery and offsite in various tributary streams both above and below Howard Hanson Dam. The exchange of genetic material between these hatchery-released coho and wild Green River coho is unknown. At present there is no effective genetic research tool for these fish

One method by which coho salmon populations may be separated is to examine differences in life histories. Life histories include geographic distribution of migration routes, timing of adult entry into freshwater, body size, coloration and time to maturation. Habitat differences include natal river origin (e.g., glacial vs. non-glacial), stream gradient, stream elevation and size of estuaries. Generally, these criteria can contribute to or reflect isolation between stocks or groups of stocks of salmon. Data has been collected on body size but they have not yet been analyzed for regional or stock differences.

The coho salmon that enter the Green River Basin are separated into two stocks (SASSI 1992), Green River coho and Newaukum Creek coho. Of particular interest is that significant differences exist in spawn timing between these stocks that might be indicative of genetic differences. Coho returning to the Green River typically spawn to mid-November. Newaukum Creek coho may spawn into mid-January (SASSI 1992 and WDFW Spawning Ground Survey Database).

As of the date of this writing an analysis for coho salmon populations has not been completed.

GREEN RIVER STEELHEAD GENETICS

NATIONAL MARINE FISHERIES SERVICE

NMFS (Busby 1996) determined that there are fifteen ESUs of west coast steelhead in California, Oregon, Washington and Idaho. Past steelhead genetic studies (Allendorf 1975; Allendorf and Utter 1979; Utter et al. 1980; Parkinson 1984) had identified two major groups along the west coast of North America. They were referred to as the coastal and inland forms. The ESUs identified by NMFS (Busby 1996) includes 12 for coastal steelhead and 3 for inland forms. Summer and winter steelhead were included in the NMFS status review of west coast steelhead (Busby 1996).

The NMFS boundaries for the Puget Sound steelhead ESU is based in part on genetic data and on life history/ecological differences. The Puget Sound ESU extends from the Nooksack River in the north through Puget Sound and west into the Strait of Juan de Fuca to Elwha River and is similar to that of chinook. The ESU includes populations of both winter- and summer-run steelhead.

There is very little information regarding the abundance of naturally produced summer-run steelhead in the Green River basin. While their numbers historically have been small, they represent a substantially different life history strategy from that exhibited by winter-run steelhead.

Green River wild winter-run steelhead are included in the Puget Sound steelhead ESU.

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

WDFW has not separated steelhead stocks into the same types of units that salmon are grouped into. This is due in part that in Washington State, Pacific salmon have been studied in greater detail than steelhead.

Phelps (1994) first reported the genetic inventory and analysis of Puget Sound steelhead stocks. That study focused on four stocks identified as critical or depressed (SASSI 1992) or for which special concerns had been identified.

There are a number of methods (Cavalli-Sforza and Edwards 1967; Nei 1978; and Saitou and Nei 1987) by which genetic differences among populations may be graphically visualized. These methods utilize different statistical analyses in which estimates of genetic distance can be displayed. Phelps (1994) found that at the first level of analysis there are three main “clusters” of steelhead stocks in Washington. This result was consistent with findings from earlier studies (Allendorf 1975; Schreck et al. 1986).

Additional analyses, based on differences through genetic analysis and displayed differently by Phelps (1994) found up to six major “clusters” of steelhead stocks in Washington state. These clusters consisted of:

- Hatchery-run strains;
- Wild Puget Sound winter-run;
- Western Washington hatchery and wild summer-run;
- Wind and Washougal rivers stocks;
- Big White Salmon and Klickitat rivers stocks; and
- Satus Creek and Wells Hatchery stocks.

The Green River wild stock was identified as being a portion of the wild Puget Sound winter-run (#2) cluster.

GREEN RIVER SOCKEYE GENETICS

NATIONAL MARINE FISHERIES SERVICE

NMFS (Gustafson 1997) summarized the presence of riverine origin spawning sockeye at several locations in the Green River and other river systems in western Washington. The Biological Review Team convened by NMFS to assess sockeye ESUs concluded that the evidence was insufficient to determine whether sockeye salmon observed spawning in rivers, including the Green River, without lake-rearing habitats were distinct populations. The status of these populations was determined to be "Uncertain" (Gustafson 1997).

Note: A single juvenile sockeye has been reported captured in the middle Green River in 1998 (Hickey pers. comm.).

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

The natural resource co-managers do not manage sockeye salmon, in the Green River, as a viable, self-sustaining population. There is the general perception that in years of sockeye abundance in the Lake Washington Basin, there are more sockeye observed in neighboring river systems.

WDFW has not initiated a genetic review of sockeye in the Green River.

GREEN RIVER BULL TROUT GENETICS

U.S. FISH AND WILDLIFE SERVICE

The U.S. Fish and Wildlife Service includes the Green River basin inside the present geographic range of bull trout in the contiguous United States. There has not been any data collected by which to genetically characterize bull trout in this basin.

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

Information on the presence, abundance, distribution, utilization and life history of bull trout in the Green River basin is either unavailable or extremely limited. Mongillo (1993) suggested the need for additional data collections. Investigations (Watson and Toth 1994, Tacoma Water HCP 1999 Draft) have not provided any evidence of bull trout spawning in the Green River Basin.

Two bull trout are reported to have been recovered in the lower river. A single bull trout was reported captured at the Soos Creek Hatchery rack in the 1956 (Beak 1996). There is no supporting data regarding this reported individual fish. This information is attributed to a personnel communication from Fred Goetz (1994).

An adult bull trout was captured by the Muckleshoot Indian Tribe at approximately RM 5 during juvenile beach seining sampling efforts in 1994 (R. Malcom. pers comm. 1999). This later fish was analyzed by the University of Washington and confirmed to be a bull trout. It is uncertain if these fish were of Green River basin origin, were of non-Green River Basin fish temporarily rearing in the Green River Basin, or were strays attempting to recolonize the basin.

No genetic samples have been obtained from this basin and the stock status can only be described as unknown. Field studies by which scientists could characterize or assess bull trout populations in the Green River basin are lacking or unavailable.

Mongillo (1993) suggested the need for additional data collections

GREEN RIVER COASTAL CUTTHROAT GENETICS

NATIONAL MARINE FISHERIES SERVICE

NMFS includes the Green River basin inside the present geographic range of coastal cutthroat. This geographical range corresponds roughly with the Puget Lowland ecoregion. This region includes all streams in Puget Sound and the Strait of Juan de Fuca west to the Elwha River inclusive. A northern boundary is unclear but unpublished data lend support to the hypothesis that it would extend into southern British Columbia (Johnson 1999). These southern and western boundaries are similar to those for chinook, coho, chum and pink salmon and steelhead. The northern boundary differs from the one for chinook, coho, pink and chum salmon.

The NMFS Biological Review Team (BRT) was unable to reach consensus on the risk for extinction of this ESU. A majority believed that the Puget Sound ESU is not presently in danger of extinction nor is it likely to be in the foreseeable future. A minority believed that the ESU is likely to become endangered in the foreseeable future.

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

Coastal cutthroat trout are managed under a species complex scenario by WDFW. This is at least in part due to multiple interacting life history trajectories. Cutthroat are found in most fish bearing waters of the Green River basin from high mountain streams downstream to estuarine habitats. Resident and anadromous forms are both found in the Green River basin.

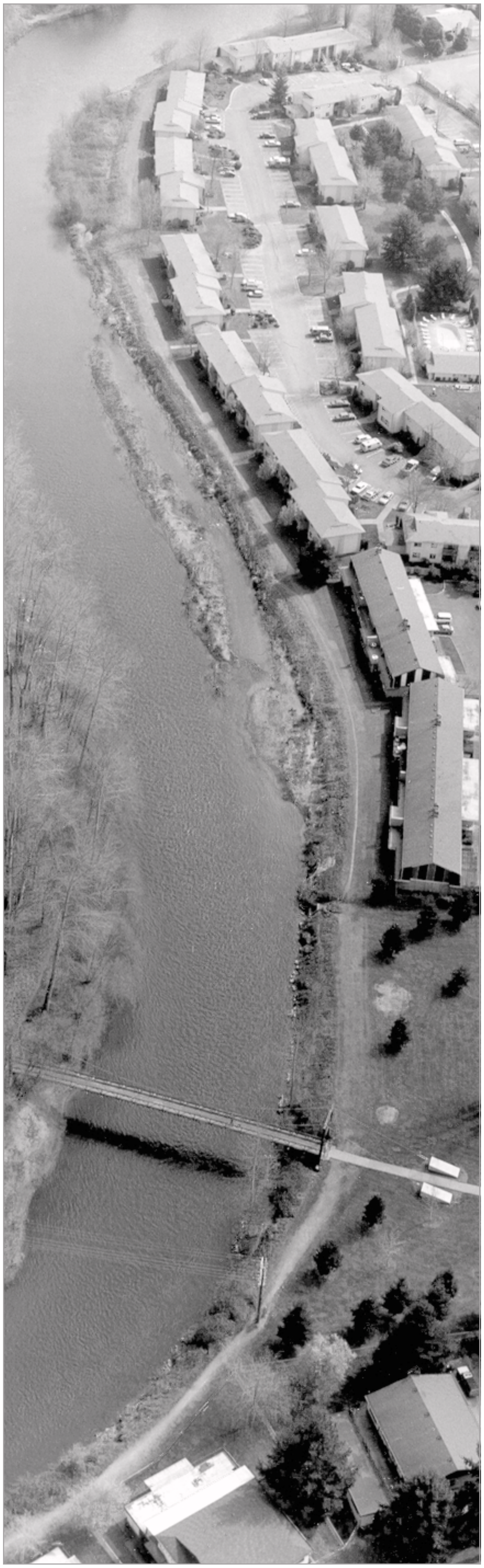
Anadromous cutthroat trout have a freshwater life history similar to steelhead. Typically, anadromous cutthroat trout smolt at two years of age and migrate in the spring into the estuary and marine near-shore habitats. These anadromous cutthroat trout may move up rivers with daily tidal fluctuations to opportunistically feed. Their ability to physiologically handle transitions between salt water and freshwater during this life phase is unique to cutthroat. Remaining in the saltwater environment for two years, these fish again migrate into their natal stream to spawn. Spawning typically occurs from January through June in small headwater streams. First time spawners typically deposit approximately 700 eggs into small gravels for incubation. Adults then return to nearshore habitats to rear again and have been known to spawn up to five times. The repeat spawners are critical to reproductive success of the species as they produce larger and more numerous eggs (Peoples 1988). These repeat spawners also provide for the exchange of genetic material between brood years.

The genetic picture for coastal cutthroat is somewhat unclear at this time. There is evidence that suggests populations are based on geographic proximity and that the Green River population is part of a larger Puget Sound population similar to what NMFS has suggested as their ESU definition.

LIST OF FIGURES

Table Gen-1. Summary of stock status, stock history and ESA status.

Figure Gen-1. Dendogram resulting from cluster analysis among Puget Sound chinook populations.



PART II
FACTORS OF DECLINE/CONDITIONS

1. Watershed-wide Conditions

2. Mainstem Green/Duwamish River Conditions

3. Tributary Conditions

4. Summary of Estuary and Nearshore Conditions

PART II: FACTORS OF DECLINE/CONDITIONS

1. Watershed-wide Conditions

1.1. Land Use

1.2. Water Quality

1.1. Land Use: Shaping the Landscape of the Watershed

1.1. Land Use: Shaping the Landscape of the Watershed

EXECUTIVE SUMMARY

An understanding of the landscape as influenced by human activities is essential to providing a full picture of WRIA 9 (Green/Duwamish River Watershed). Land use activities from forestry to agriculture to urbanization have shaped the landscape of WRIA 9 for the past 150 years. This report discusses how human land use activities can influence watershed processes and salmon habitat, provides information about the historical and current land uses in the watershed, and notes the policies that have shaped and continue to shape the watershed's land use and land cover.

Over the past 20 years, a significant amount of research has been done in the Pacific Northwest and the Puget Sound area regarding the impacts on streams and wetlands by various land use practices. Human activities such as forestry, agriculture, urbanization, and mining can drastically disrupt aquatic ecosystems by altering watershed ecological processes either directly or indirectly. Disruptions can include degradation or destruction of in-stream habitat through clearing of riparian vegetation, channelization and bank armoring, barriers to salmonids by dams or other water diversions, increased peak runoff rates and volume of surface water runoff, and removal of wood and reduction of wood recruitment. All of these activities in turn impact hydrology, water quality, riparian functions, and other factors of decline.

WRIA 9 was one of the first areas of Puget Sound extensively settled by immigrants in the late 18th century**.** As the Native American populations declined, the settlers began to occupy the vacated lands. The settlers employed various methods and policies to gain economic benefit from the land. The 19th century and the early 20th century brought land clearing for agriculture, commercial forestry, channelization for navigational purposes, diversion of major Green/Duwamish tributaries to reduce flooding, and filling of tidelands for development. Various federal, state, and local policies allowed and even encouraged these activities to occur.

During the middle of the 20th century, economic development fostered leveeing and damming to reduce flooding, road building and transportation infrastructure construction, and industrial, commercial, and residential development. Again, federal, state, and local policies encouraged this type of development. During the last 30 years of the 20th century, government agencies and the public began to support environmental protection measures and growth management. The federal government passed environmental legislation to protect undeveloped land, wetlands, shorelines, and endangered species habitat. State and local government began to embrace policies to manage development growth, protect shorelines, protect undeveloped land, protect wetlands, and protect farmlands. The effectiveness of these policies varies due to a variety of constraints including overlapping and conflicting regulatory goals.

Today, 97 percent of the Green/Duwamish River estuary has been filled, 70 percent of the area of the former Green/Duwamish River Watershed has been diverted out of the drainage basin, and about 90 percent of the once-extensive floodplain of the Green/Duwamish River is no longer inundated on a regular basis (Fuerstenberg, 1999).

The land area of WRIA 9 is 568 square mile area. Thirty percent of the WRIA is within the Urban Growth Area (UGA). The land in the Upper Green River Sub-watershed is primarily managed forest. The Middle Green River Sub-watershed is primarily farmland and a mix of urban and rural residential. The Lower Green River Sub-watershed contains less farmland and is urban in nature. The Duwamish Estuary Sub-watershed is predominantly urban residential, commercial, and industrial. Nearly all the Nearshore Sub-watershed is also urban residential while the Vashon Sub-watershed is rural residential.

Population has increased dramatically since the beginning of the 19th century. In the early 20th century, the region experienced a dramatic increase in population predominantly in the urban areas such as Seattle and the other watershed cities. As the Puget Sound population centers continued to expand through the 1970s, 1980s, and 1990s, WRIA 9 has experienced increasing urbanization throughout its UGA. In 1999, population in WRIA 9 was estimated at 563,980 (adapted from PSRC data, 2000). About 89 percent live in the UGA and 11 percent live in the Rural Area or Resource Lands.

KEY FINDINGS

- Effects of land use on habitat range from elimination of habitat to degradation of habitat quality to mitigation for environmental damages under existing regulations.

- Historically, local, state, and federal policies have greatly influenced the amount and type of land use that has occurred in WRIA 9:

  - By the early part of the twentieth century, the region and state planned to develop the Duwamish River and Lower Green into the main industrial area in the county and Puget Sound region.

  - For the first 120 years of settlement, economic development was the predominant driver of growth and development.

  - For the last 30 years, development has occurred under an increasing number of environmental protection policies and growth management policies.

  - Specific actions were taken over many years to enable economic growth and develop natural resource industries.

  - Many policies have been established in the last 30 years that require sound planning and development at both the regional and local level.

  - Meeting multiple objectives for the Growth Management Act, the Endangered Species Act, and other complex regulations creates a challenging, overlapping framework for regulations and protections.

- The seven years from 1910 to 1916 saw the most dramatic hydrologic change. During this time period, 70 percent of the acreage of the Green/Duwamish Watershed was diverted away from the original Green/Duwamish River and a dam was constructed that blocked fish access to 45 percent of the remainder.

- Growth management is having a significant influence on directing growth to the Urban Growth Area (UGA) and reducing sprawl. However, as population increases, there is a corresponding increase in the amount of developed land:
  - Growth indicators suggest that the UGA is large enough to accommodate projected growth through 2012.
  - Eighty nine percent of the population of WRIA 9 is concentrated in the UGA.
  - Thirty percent of WRIA 9's land area is within the UGA.
- Most of the urban land uses are located in the western third of the WRIA while the middle and upper portions of the WRIA are primarily rural and natural resource lands:
  - Forestry is the primary designated land use at 99 percent in the Upper Green River sub-watershed.
  - Residential development (50 percent), forestry (27 percent) and agriculture (12 percent) are the primary land uses in the Middle Green River sub-watershed.
  - Residential development (50 percent), industrial development (17 percent), and commercial development (10 percent) are the primary uses in the Lower Green River sub-watershed.
  - Industrial development (43 percent) and residential development (39 percent) are the primary designated land uses in the Green/Duwamish Estuary Sub-watershed.
  - Residential development (68 percent) and industrial development (10 percent) are the primary designated land use in the Nearshore Sub-watershed.
  - Residential development at 92 percent is the primary designated land use in the Vashon-Maury Island Sub-watershed.
- Population growth has been a driving factor for the rapid development rates in the watershed:
  - Before 1996, the majority of jurisdictions in WRIA 9 were experiencing a 1 percent per year or higher population growth rate.
  - Population growth has slowed since 1997 to less than 1 percent per year overall in King County.
  - Every 1 percent increase in population growth corresponds with a 2 percent or higher increase in developed land during the 1990s.

DATA GAPS

Land use information currently available presents certain challenges. The information is not currently organized by watershed boundaries. Although a great deal has been written regarding land use and its effect on salmonids, there has not yet been a close look at local regulations and the subsequent effects on salmonid habitat. Below are the identified land use data gaps:

- Prepare land development and demographic information for King County by boundaries of the Water Resource Inventory Areas, sub-watersheds, and basins.
- Inventory permitting and regulatory processes (SEPA and Shoreline review, permit review, sensitive area review, ordinance and regulatory review) throughout the WRIA. Assess the biological implications of various land use activities, regulations, and policies.
- Inventory impervious surface areas (location and amount), road densities, and forest cover retention at a sub-watershed or smaller scale.

EFFECTS OF LAND USE ACTIVITIES

Over the past 20 years, a significant amount of research has been done in the Pacific Northwest and the Puget Sound area regarding the impacts on streams and wetlands by various land use practices. Human activities such as forestry, agriculture, urbanization, and mining can drastically disrupt aquatic ecosystems by altering watershed ecological processes either directly or indirectly. Disruptions can include degradation or destruction of in-stream habitat through clearing of riparian vegetation, channelization and bank armoring, barriers to salmonids by dams or other water diversions, increased peak runoff rates and volume of surface water runoff, and removal of wood and reduction of wood recruitment. All of these activities in turn impact hydrology, water quality, riparian functions, and other factors of decline.

Below in table LU-1 is an overview and summary of possible impacts to the natural aquatic system due to human uses. Each of the individual factor of decline reports conducted for the WRIA 9 Reconnaissance Assessment discusses these impacts in more detail. For example, the hydrology chapter discusses impacts of dams, increased storm and surface water runoff, and water use on the natural flow regime; the hydromodifications chapter illustrates loss of salmon habitat due to human influenced changes to the river channel; and the sediment transport chapter highlights increased erosion and sedimentation as a result of forestry practices.

Table LU-1. Overview of Possible Impacts of Human Land Use to Natural Aquatic Systems (adapted from Tri-County Urban Issues Study, R2 Resource Consultants, 1999).	
Land Use and Human Activities	**Potential Result and Impact of Salmon Habitat**
Channelization and confinement of stream channels for urban and rural land uses	Reduced channel complexity; increased velocities; loss of pools for holding and rearing; loss of spawning gravel habitat; loss of side channels; loss of wood recruitment; loss of connectivity with flood plain and riparian zone ***(reduced quality and quantity of habitat)***
Loss of riparian vegetation due to urbanization, mining, forestry, agriculture, etc.	Reduced overhanging vegetation and shade cover; increased solar radiation; elevated water temperatures; loss of LWD recruitment; reduced terrestrial insect influx; reduced leaf litter influx; alteration of energy cycle ***(reduced quality and quantity of habitat)***
Loss of forested areas due to urbanization, mining, forestry, agriculture, etc.	Reduced effective watershed area; altered runoff cycle with altered timing and magnitude of flows; increased erosion; changed channel morphology ***(reduced quality and quantity of habitat)***
Loss of wetlands due to urbanization, mining, forestry, agriculture, etc.	Altered runoff cycle with altered timing and magnitude of flows; reduced base flows; changed channel morphology and loss of connectivity with floodplain ***(reduced quality and quantity of habitat)***
Creation of impervious surfaces	Altered runoff cycle with altered timing and magnitude of flows; changed channel morphology; degraded water quality increased stormwater runoff ***(reduced quality and quantity of habitat)***
Water allocation	Altered flow regime; altered instream habitat availability ***(reduced quality and quantity of habitat)***
Waste water treatment effluent	Degraded water quality related to sewage effluent; altered water temperatures; reduced dissolved oxygen concentrations; released contaminants ***(reduced quality and quantity of habitat)***
Industrial effluent	Degraded water quality; released contaminants and toxins ***(reduced quality and quantity of habitat)***
Culverts, pipes, ditches	Obstructed upstream passage; reduced downstream movement of wood and gravel; stranded fish in ditches ***(reduced quality and quantity of habitat)***
Loss of estuarine and nearshore habitats; port development	Loss of important freshwater to saltwater transition habitats, including cover and food production for smolts; loss of staging and holding habitats for adult salmon; degraded water quality ***(reduced quality and quantity of habitat)***
Bulkhead and dock construction	Increased habitat for predators (e.g., bass); altered nearshore currents and gravel movement; loss of eelgrass habitat ***(increased interaction with predators; reduced quality and quantity of habitat)***
Erosion and sedimentation	Increased turbidity and inputs of fine sediment during construction and prior to revegetation ***(reduced quality and quantity of habitat)***
Water related recreational activities	Increased potential direct contact with ESA-listed salmon; degraded water quality (e.g., fuel spills) ***(reduced quality and quantity of habitat)***
Fertilizer and pesticide use*	Degraded water quality and increased toxicity; biological degradation ***(reduced quality and quantity of habitat)***
Dams*	Loss of upstream habitat due to obstructed upstream passage; altered timing and magnitude of flows; reduced base flows; changed channel morphology; reduced downstream movement of wood and gravel; and loss of connectivity with floodplain. ***(reduced quality and quantity of habitat)***
* Information taken from "An Ecosystem Approach to Salmonid Conservation" (Spence et. al., 1996)	

With over 400 reports and studies looking at impacts of land use on habitat, a thorough review of all the literature covering human impacts on natural systems is beyond the scope of this chapter. Initial studies on effects of urbanization on the aquatic system in the Northwest focused on the impacts of urbanization on peak-flow increases. In 1975, Hollis synthesized separate studies to show how the dual factors of percent impervious surfaces and percent of a watershed in storm sewers increased the peak discharges of floods. Then in 1979, Klein published the first study correlating development and aquatic-system conditions in which he reported a rapid decline in biotic diversity where watershed imperviousness exceeded 10 percent (Booth, 2000).

Subsequent studies and models on the subject done throughout the 1980s and 1990s built upon this initial research. Results of research done to date have several overall implications: (1) “Imperviousness,” although an imperfect measure of human influence, is clearly associated with stream-system decline. A range of stream conditions, however, can be associated with any given level of imperviousness; (2) “Thresholds of effect,” identified in some of the earlier literature (e.g., Klein, 1979; Booth and Reinelt, 1993 referenced in R2, 2000) exist largely as a function of measurement precision, not necessarily as intrinsic characteristics of the system being measured. Crude evaluation tools require that large changes accrue before they can be detected, but lower levels of development may still have consequences that can be revealed by other, more sensitive methods. In particular, biological indicators demonstrate a continuum of effects resulting from human disturbance; and (3) Hydrology is not the sole determinant of stream conditions, but its effects are ubiquitous in urban systems (Booth, 2000).

One of the most comprehensive of the recent studies on impacts of urbanization on aquatic systems was conducted by Chris May et al. The resulting report, titled “Quality Indices for Urbanization Effects in Puget Sound Lowland Streams,” was published in 1997 for the Department of Ecology. The study collected and analyzed data from 22 Puget Sound lowland streams representing a range of development intensity from predominantly rural watersheds to watersheds that were 99 percent urban. The researchers measured stream habitat conditions, water quality, sediment composition, sediment contamination, fish populations, and benthic organisms at each study site and compared them to watershed conditions. The results demonstrated that the greatest impacts of urbanization to streams typically include:

- Changes in hydrology;
- Changes in riparian corridor;
- Changes in physical habitat; and
- Water quality (R2, 2000).

The frequency, volume, and quality of large woody debris also decreased significantly as basin development increased. In general, fine sediment in spawning gravels generally increased as urbanization increased while intragravel dissolved oxygen decreased. The study further found that as the level of basin development increased above 5 percent total impervious area, results indicated an initial decline in biological integrity as well as physical habitat conditions necessary to support natural biological diversity and complexity (May et al., 1997). One interesting finding of the May et al. report was that the density of the road network could be used, similarly to total impervious area, as an indicator of impacts to stream conditions. This is primarily because of the drainage system associated with most roads (R2, 2000).

Less information is available regarding the impacts of urbanization on Puget Sound salmon habitat in nearshore environments, estuaries, large rivers, and lakes. In general, changes in hydrology, pollutants, and physical habitat structure in these environments may cause ecological impacts that are comparable to the findings from freshwater research (R2, 2000). Study results have indicated that in the Duwamish and Puyallup estuaries, contaminant exposure in juvenile chinook was likely from the consumption of benthic and epibenthic organisms, which inhabit the contaminated estuarine sediments in these basins (R2, 2000). Some studies have suggested that suppressed immune systems in young salmon could make the fish more susceptible to disease as they move further into the marine environment (R2, 2000).

Below is a list of resources with more information on the impacts of urbanization on aquatic systems.

- The ESA Urban Issues Document Library and Database contains over 400 documents including documents from federal, tribal, state, and local agencies, as well as scientific articles that were published in peer-reviewed journals.

- Forest Cover, Impervious Surface Area, and the Mitigation of Urbanization Impacts in King County. (Derek Booth, Center for Urban Water Resources Management, University of Washington, September 2000) discusses impacts from urbanization on hydrology of aquatic systems.

- Tri-County Urban Issues Study (R2 Consulting, February 2000) reviews and consolidates existing information related to impacts of urbanization on natural aquatic systems, summarizes current management activities to mitigate these impacts, and presents guidance in selecting salmon recovery options in urban and urbanizing areas.

- An Ecosystem Approach to Salmonid Conservation (Brian C. Spence et al., December 1996) provides a technical basis for implementation of an ecosystem approach to habitat conservation planning. Chapter 6 discusses effects of human activities on watershed processes, salmonids, and their habitats.

- Quality Indices for Urbanization Effects in Puget Sound Lowland Streams (Chris May et al., June 1997) reports on a study of instream habitat, riparian conditions, water quality, and biological attributes of 22 streams to determine the relationships between urbanization and stream quality.

- Factors Affecting Chinook Populations (Parametrix, June 2000) is a “snapshot” of what is currently known about how development in the City of Seattle has affected chinook salmon.

HISTORIC POLICY CONTEXT AND LAND USE EVENTS

WRIA 9 was one of the first areas of Puget Sound extensively settled by immigrants**.** Today, 97 percent of the Green/Duwamish River estuary has been filled, 70 percent of the area of the former Green/Duwamish River Watershed has been diverted out of the drainage basin, and about 90 percent of the once-extensive floodplain of the Green/Duwamish River is no longer inundated on a regular basis (Fuerstenberg, 1999).

The land in the Upper Green River Sub-watershed is primarily managed forest. The Middle Green River Sub-watershed is primarily farmland and a mix of urban and rural residential. The Lower Green River Sub-watershed contains less farmland and is urban in nature. The Green/Duwamish Estuary Sub-watershed is predominantly urban residential, commercial and industrial. Nearly all the Nearshore Sub-watershed is also urban residential while the Vashon Sub-watershed is rural residential.

OVERVIEW AND CHRONOLOGY OF WATERSHED LAND USE CHANGES

The WRIA 9 land use history began several thousand years ago when indigenous people first moved into the WRIA 9 (Green/Duwamish Watershed). However, a great preponderance of the major land use changes has occurred in the last 150 years since settlers moved into the area. Table LU-2 shows a chronology of the land use events and policies affecting WRIA 9 beginning in 1790 and ending in 2000 (Fuerstenberg, 1999). The scope of this chronology does not include tribal history prior to 1790.

Table LU-2. Chronology of Policies and Events in the WRIA 9: 1790-2000 (adapted from Fuerstenberg, 1999).		
Date	**Policies and Events**	**Notes**
1790s	First settlers move into the Puget Sound area	
1840s	Native populations in the WRIA decreased to one tenth of 1790 population levels	Settlers move into unoccupied lands
1850	Oregon Donation Land Act	Granted land to settlers if they homestead for 5 years
1851	First settlers arrive in the Duwamish estuary area	Land clearing begins - three claims filed
1852	King County is established	Settlers' first major governance system in WRIA
1852	Livestock introduced into Lower Green River Valley	Grazing begins on land
1853	Washington Territory is established	
1853	Extension of Land Act through 1855	Seventeen claims filed along the river
1854	First road built in King County	Road built through the lower river valley
1855	Treaty of Point Elliott	Establishment of Muckleshoot and Duwamish Reservations
1855-58	State requests Congressional funding for river clearing	River boat/scow major mode of travel along the Green/Duwamish River - removal of debris from river done for navigation purposes
1855-56	Indian Wars	Settlers move to Seattle for protection - settlement slows
1856	Land clearing resumes	Duwamish area gardens planted, orchards established, wide scale timber cutting begins
1858	King County Drainage Laws	County passes laws permitting ditches for drainage, swampland drainage begins
1862	Homestead Act	Settlement of territory encouraged
1865	City of Seattle is established	
1866	Population of valley starts to grow in earnest	Development increases
1867	First RR bridge built across Black River	Local railroad construction begins in area
1870	277 settlers living in valley	
1870s	Major railroads build lines	Pace of logging increases in WRIA 9
1875	Channel Improvement Act	County road funds used for improvement of rivers
1878	Golden Age of Hops begins	Hops production popular, continues for 20 years
1880-1910	Majority of logging occurs in WRIA 9	
1888	Northern Pacific Railroad constructs east/west line through Green/Duwamish River Watershed	Logging camps such as Borup, Kennedy, Nagrom and Maywood, and town of Lester, are established
1889	Washington granted statehood	
1893	Great Northern Railroad develops lines in north/south direction in valley	
1895	Drainage District Act	County Drainage Districts formed
1895	Duwamish East Waterway construction begins	Duwamish East Waterway dredged and used for Harbor Island fill
1897	Federal Government creates forest reserve that later becomes Snoqualmie National Forest	Curtails further development in the Upper Green River Sub-watershed
1899	Federal Rivers and Harbors Act	Encouraged federal actions to protect navigation rights
1900	Extensive logging on Vashon Island	Little old growth forest remains on Vashon Island
1902	Green River Hatchery completed	State-operated Green River Hatchery opens on Soos Creek
1901-04	Hydraulic sluicing of Beacon Hill in Seattle	Fill placed in the intertidal area of the Duwamish River to raise land and decrease flooding potential
1906	Major flooding in rivers during fall and winter	Log jam on lower "White River" forces floodwater down the Stuck River into the Puyallup River
1902-27	Interurban Electric railway operates	Interurban eclipses Green/Duwamish River as a means of travel
1910	Tacoma Headworks dam authorized	Construction begins on Tacoma Headworks on Green River to provide water for the City of Tacoma
1911	White River Diversion	White River completely diverted to Puyallup River to reduce flooding problems
1913	Tacoma Headworks completed	Drinking water diverted from Green River for the City of Tacoma
1916	Black and Cedar Rivers diverted from Duwamish and Ship Canal cut to Lake Union draining Lake Washington to Puget Sound	This diversion reduced flooding in the Duwamish River lowlands, provided flushing for Lake Washington, and created access to fresh water for ships
1917	East/West Waterways finished	Dredging of channel completed, 2.2 sq. miles of Duwamish intertidal area filled - reduces potential flooding
1918	Coal production peaks and is one of the state's largest exports	Renton and Black Diamond coal mining peaks
1919	Private levee construction begins	Levees built to protect lowlands from flooding all along the Green/Duwamish River

Table LU2. Chronology of Policies and Events in the WRIA 9: 1790-2000 (adapted from Fuerstenberg, 1999) (Continued).		
Date	**Policies and Events**	**Notes**
1926	King County Planning Commission appointed and releases recommendations	Report includes preparation of county road plan, acquisition of parks, regulation of platting, and formation of a metropolitan sewer district
1935	Washington State Planning Enabling Act	Counties and jurisdictions allowed to regulate land use
1938	The first soil survey was initiated as a cooperative effort of the United States Department of Agriculture (USDA), the Washington Agricultural Experiment Station, and the Washington State Planning Council	Described and located numerous types of soil and documented the productive capacity of various soils for different types of agricultural crops
1949	Tacoma Water signs cooperative agreement with all major land owners in Upper Green	Agreement leading to a limit of activities that affect water quality, access, and fish habitat
1954	City of Seattle, King County, and Port of Seattle release the Development Plan for the Duwamish and Lower Green River	Recommends constructing Howard Hanson Dam, converting 2,500 acres of farmland to industrial area, expanded dredging of the river and filling of the estuary
1957	Duwamish Valley Study released by King County Planning Commission	Recommends construction of highway project that affect the Green/Duwamish basin (e.g., I-5, I-405, SR 18, SR 167, SR 516)
1963	Howard Hanson Dam completed	Reduces maximum flow of Green River to 12,500 cfs at Auburn to reduce flooding potential
1964	King County adopts its first comprehensive plan	Recognizes the need for an effective means of guiding and coordinating the physical development of the County; a means for coordinating programs and services; a source of reference to aid in developing coordinated official plans and regulations for the County and municipalities within it; and a means of promoting a desirable environment for housing, commerce, industry, agriculture, and recreation
1970	National Environmental Policy Act	Requires environmental review for all development with a federal nexus
1971	Washington State Shoreline Management Act	Requires local jurisdictions to create master plans that protect coastal resources while also allowing development activities
1972	Federal Coastal Zone Management Act	Unique federal/state partnership to encourage states to develop programs that preserve, protect, and restore coastal resources
1973	Washington State Land Use Act	Allowed lands that are undeveloped and left in the natural state to be taxed at a lower rate than developed land
1973	Federal Endangered Species Act	Federal agencies required to protect endangered species and their habitat from harmful human activities
1974	Boldt Decision	Washington State Supreme Court interpreted the Treaty of Point Elliott to mean that Native American tribes were entitled to half of the total allowable catch of fish in the tribe's usual and accustomed fishing grounds
1977	Clean Water Act (Amendment to the Federal Water Pollution Control Act of 1972)	Generally halted filling of wetlands or required mitigation for filling of freshwater or marine wetlands
1978	King County Growth Management Program	Directed future comprehensive plans to deal with growth while incorporating environmental protection, energy conservation, and farm land preservation
1979	King County voters pass Farmland Preservation Program	$50 million bond issue to purchase development rights on agriculture lands in King County
1985	King County Comprehensive Plan--1985	Addressed expected population and employment growth; established urban areas, transitional areas, rural areas, open space, and natural resource lands
1990	Washington State Growth Management Act	Requires local governments to plan for growth; all urban counties and their cities are required to plan comprehensively and jointly for the future
1994	King County Comprehensive Plan--1994 Cities begin to adopt comprehensive plans County and city plans are guided by the Countywide Planning Policies	Urban Growth Area established in the western one-third of the County where most future growth and development will occur to reduce urban sprawl, enhance open space, protect rural areas including the establishment of the Agriculture Production District, and more efficiently use human services, transportation, and utilities
1998	Washington State Department of Ecology initiates an update of the Shoreline Master Program guidelines	
1999	Federal listing of chinook salmon and bull trout as threatened species	Protection and recovery of species in Puget Sound Region is required

PRE-1850: THE YEARS BEFORE THE SETTLERS

Before settlers arrived in the region, streams of the Puget Sound lowland were a network of sloughs, islands, beaver ponds, and estuaries (Fuerstenberg, 1999). Historians estimate about 300 Native American people lived in the Tukwila area in the 18th century and fewer than 4,000 Native American people lived throughout the Duwamish River area (Fuerstenberg, 1999). Primary activities of native people were fishing, hunting, and food gathering. Shellfish and salmon were the primary foods of Native Americans. Gardens and camas fields (maintained by burning) were the only evidence of forest clearing by Native Americans.

1850-1917: SETTLERS AND THE YEARS OF RESOURCE EXTRACTION

SETTLERS LAND USE POLICY—1850-1917

Human Settlement

Native peoples including the Muckleshoot Tribe have lived in the WRIA 9 watershed for thousands of years. However, the native peoples' land use and natural resource use patterns were less disruptive to the natural ecosystem than the settlers' subsequent land use patterns. The Treaty of Point Elliott signed in 1855 allowed the settlers to begin to dominate land use in the watershed. This treaty moved tribes to reservations that were a fraction of the land area that the tribes used to occupy. The federal policies of "manifest destiny," the Donation Land Act of 1850, the Homestead Act, and the laissez faire economic policies of the federal government influenced the settlers' development of the Green/Duwamish River Watershed. The results of these policies were the rapid settlement of the area and the exploitation of natural resources. (Benoit, 1979)

Navigation/Transportation

The Green/Duwamish River was a significant transportation corridor during early settlement, fostering development of communities along the edge of the river. As communities sprang up, the shorelines were cleared and adjacent wetlands were drained under drainage laws established by King County in 1858. Policies that encouraged these settlements and federal policies that encouraged use of the river for navigation, resulted in extensive development of land for agriculture. In turn, the agricultural development in the Duwamish area supported the growth of communities near Elliott Bay.

As the land was settled, federal policy encouraged the expansion of the railroad. Three distinct land use patterns developed as a direct result:

- Federal land grants to railroads resulted in the checkerboard pattern of land ownership in the Upper Green River Sub-watershed that influences patterns of forestry activity even today;

- The routes taken shaped the growth of local communities and industry; and

- Later patterns of highway development were influenced by early rail routes, thus further reinforcing the development of commercial and industrial land uses in the valley.

The Federal Rivers and Harbors Act of 1899 provided the policy basis for federal actions in and around the navigable waters of King County and gave responsibility for conducting water projects to the U.S. Army Corps of Engineers. In 1910, construction of the Hiram M. Chittenden Locks and the Lake Washington Ship Canal occurred under the auspices of the Rivers and Harbors Act. These major projects diverted the Cedar River and Lake Washington outflow via the Black River away from the Duwamish estuary and into Puget Sound via the ship canal and locks. The policy basis for improving the transportation corridor of the Lake Washington system reinforced other policy choices that gave greatest prominence to the use of the Duwamish estuary for industrial development.

Tidelands Development

The State Constitution established the policy basis for filling of the Duwamish estuary and the resultant industrial land uses that still prevail there today. The State Constitution (Article XV-XVII) established state ownership of tidelands and required that tidelands should be "reserved for lands, wharves, streets, and other conveniences of navigation…" In 1894, the State Legislature authorized any person or company to excavate waterways through the tide and shorelands in front of incorporated cities, giving individuals or companies a first lien upon any lands they filled in, for the cost of the work plus, fifteen percent added to the lien on the lands benefited. This provided a financial incentive to develop the Duwamish estuary for industrial and commercial uses. Because much of the land in the downtown area was on fairly steep slopes that were largely unsuitable for industrial and commercial uses, the filled shoreline areas were rapidly developed for such purposes.

Reinforcing State policies that viewed estuaries as ripe for industrial and commercial development, the State established the legal basis for special waterway districts. The East Waterway district of the Duwamish River was among the first of such districts established (Warren, 1997).

Adding to this development, at the time of statehood, ownership of all tidelands in Washington State was transferred from the federal government to the state under the equal footing doctrine of the U.S. Constitution (Good and Ridlington, 1992). The tidelands were supposed to be held in the "public trust" per the Public Trust Doctrine, which is a common law doctrine protecting shorelands in the public interest. Over time, 70 percent of Washington's inland marine water tidelands were sold to private upland owners (Broadhurst, 1998). The Public Trust Doctrine and the "takings" clause of the Fifth Amendment of the U.S. Constitution protecting private property rights have been invoked many times in court battles over shoreline land use since the beginning of the 20th century.

Flood Control

The nation had long been engaged in issues of flood control, especially in the Mississippi River basin (MRC, 2000). Flood control measures in this region of the United States influenced the policy foundation for flood control in WRIA 9, including the White River diversion in 1911 (Bagley, 1929) and Howard Hanson Dam construction in 1963. The purpose of flood control was to protect the economic well-being of the region by preventing floods, such as one in 1906, which disrupt agricultural land uses. The diversion of the White River was only one of several steps taken from the early 1900s to the present to control flooding within WRIA 9.

Commercial Forestry

Land dedicated to railroads was often transferred to subsidiary commercial forestry companies (e.g., Plum Creek Timber Company was originally part of Burlington Northern, which was the successor company to both the Great Northern and the Northern Pacific Railroads) or sold to other commercial forestry interests. In addition, the federal government, recognizing the value of forestlands, established a policy to create federal forest reserves in 1897. The creation of the Snoqualmie National Forest and a federal policy of allowing logging on public lands, ensured that land uses in the Upper Green River Sub-watershed would focus on timber production and mineral extraction. The National Forest Management Act later broadened the mandates of federal forestlands to include recreation, fish and wildlife habitat, and other designated forest uses.

SETTLERS LAND USE PATTERNS 1850-1917

After Euro-Americans arrived in the 1850s, the landscape changed dramatically. The Treaty of Point Elliott in 1855 moved native peoples to a small reservation in WRIA 9, allowing Euro-Americans to move further into areas previously occupied by native peoples. WRIA 9 was among the first areas west of the Cascade Mountains to be logged (Fuerstenberg, 1999). By 1895, the riparian zone had been logged from the mouth of the Duwamish River to Horseshoe Bend near Kent. From Horseshoe Bend to Big Soos Creek, the riparian area was a mix of intact trees and areas that had been burnt or cleared. Above the confluence of Soos Creek and the Green River, the riparian area was cut or cleared (Fuerstenberg, 1999).

In 1888, the Northern Pacific Railroad was the first transcontinental railroad to the Pacific Northwest and made almost all parts of the basin accessible to timber production (Fuerstenberg, 1999). The railroad companies acquired land from the federal government and transferred it to Plum Creek or sold the land to other timber companies. Subsequent logging operations supplemented by frequent forest fires greatly depleted the original forest (Fuerstenberg, 1999). In a survey from 1853 to 1861 of plant life west of the Cascades for the Northern Pacific Railroad, Cooper notes the excellent firewood characteristic of Douglas fir, “From its combustibility extensive tracts of this forest get burnt every year, taking fire from friction or any other slight cause.” Cooper described ascending the western slopes of the Cascade Range where “we passed for days through dead forests.” As the Northern Pacific Railroad had not yet constructed its line through the Green/Duwamish River watershed, Cooper probably observed and recorded evidence of natural fires in the Green/Duwamish River watershed or natural fires fostered by poor logging practices (Fuerstenberg, 1999).

Before 1900, settlers established orchards and farms along the Lower Green River. As land was cleared, tree stumps were usually discarded in the river. Levees and revetments were constructed along segments of the river to protect farms and homesteads from flooding and erosion. Around the turn of the century, Vashon Island was extensively logged and, with the exception of a small stand of privately owned trees in the Christensen Creek area, few trees over 100 years old remained (Thomas, 1979). Commercial forestry had also begun along the tributaries and along the Green River mainstem leaving logging debris in the channels. In the 1850s, logs began to be removed from the river to allow riverboats, an early mode of transportation in the valley, to navigate. Flooding continued to be a problem for people in the valley. In 1906, major flooding occurred on the White and Green Rivers (Fuerstenberg, 1999).

As the land was cleared of vegetation for commercial forestry and agriculture operations, protection was needed from flooding and the excess water generated by lack of forest cover. (A 1919 Washington State Fish Commission report noted that "...as timber is cleared away, hatchery operations are more and more hampered by flood conditions. The water in streams rises more quickly now than was formerly the case when there was heavy timber growing...") Extensive levee and revetment construction began in about the same year. Flood-prone valley areas along the Green/Duwamish mainstem and the estuary were drained and filled, and major tributaries were rerouted or disconnected from the Green (Fuerstenberg, 1999).

Replumbing of the Green

The seven years from 1910 to 1916 saw the most dramatic hydrologic change. During this period, 70 percent of the land area of the Green/Duwamish Watershed was diverted away from the original Green/Duwamish River and a dam blocked fish access to another 10 percent of the land area of the original Green/Duwamish Watershed. These activities were a major disruption to salmon and other aquatic species migration and rearing.

In 1910, the Cedar, Black, White, and Green Rivers combined to form the Duwamish. After the large flood of 1906, plans to divert the White River permanently to the Puyallup River were made by the U.S. Corps of Engineers. In 1911, this diversion was completed (Fuerstenberg, 1997). One of the effects of this diversion was to reduce the volume of water flowing in the lower portion of the Green/Duwamish River (Fuerstenberg, 1999).

In 1913, the City of Tacoma completed its Headworks water diversion dam on the Green River near the town of Palmer. The Headworks further reduced the flow and shut off the Upper Green River Sub-watershed to anadromous fish passage. The State granted Tacoma Water (now known as Tacoma Public Utilities) the right to remove a maximum of 113 cfs of water from the River. Tacoma Water subsequently began purchasing land adjacent to the river in the Upper Green River Sub-watershed to protect water supply operations, although Tacoma still allows logging in certain portions of the riparian area (TPU, 1998).

By 1916, the Black and Cedar Rivers had been diverted from the Duwamish River as part of a project to connect Lake Washington and Puget Sound. This diversion reduced flooding in the Duwamish River lowlands, thereby allowing more development. This diversion provided flushing for Lake Washington and navigational access from Puget Sound to Lake Washington via the Hiram M. Chittenden Locks and the Lake Washington Ship Canal. As a result, the Cedar River now flows into Lake Washington while the Black River has been reduced to a fraction of its former volume and is disconnected from Lake Washington (Fuerstenberg, 1999).

In 1854, 1900 linear miles of stream and river were accessible to fish through the Duwamish River. By 1985, fish could access only 125 river miles through the Duwamish River. The entire lengths of the White and Cedar Rivers remain accessible to fish through the Puyallup River and Lake Washington Ship Canal, respectively (Fuerstenberg, 1999).

1917-1970: THE YEARS OF ECONOMIC DEVELOPMENT

ECONOMIC DEVELOPMENT POLICY—1917-1970

Flood Control

At the federal level, continued discussion of flooding on the Mississippi River provided the basis for approaches to further control flooding in the Green River valley (MRC, 2000). Private levees that had been permitted by State and County legislation were supplemented by publicly financed levee construction under the Flood Control Act of 1936 (33 USC Chapter 15). The U.S. Army Corps of Engineers took the lead in creating a system that would protect the agricultural, commercial, industrial, and residential land uses that were growing throughout the region. This policy was followed by the Watershed Protection and Flood Prevention Act of 1954, which reaffirmed previous policy (16 USC Chapter 18). The Act stated:

> *"Erosion, flood water, and sediment damages in the watersheds of the rivers and streams of the United States, causing loss of life and damage to property, constitute a menace to the national welfare; and it is the sense of Congress that the Federal Government should cooperate with States and their political subdivisions, soil or water conservation districts, flood prevention or control districts, and other local public agencies for the purpose of preventing such damages, of furthering the conservation, development, utilization, and disposal of water and protecting and improving the Nation's land and water resources and the quality of the environment."*

The Howard Hanson Dam was constructed in 1963. Its primary purpose was flood control by holding back peak flows and attenuating their release over a long duration in the spring in order to protect developing cities like Auburn, Kent, and Tukwila from flood damage. With assurances that development would not be flooded, industrial, commercial, and residential land uses in the valley burgeoned while agricultural uses diminished. The population of the City of Auburn increased 121 percent between 1960 and 1980. During the same period, the City of Kent grew 157 percent while the City of Seattle saw a population decline of 11 percent . King County, as a whole experienced population growth of about 35 percent (Washington State Office of Financial Management, 2000).

Transportation

Federal highway construction policies emphasize increasing freight mobility across the continent. Federal funding for construction of Interstate 5 and Interstate 90 encouraged the development of industry in the Green/Duwamish River Watershed. In 1957, the King County Planning Commission released the "Duwamish Valley Study." This study recommended the current locations for the major highway systems in WRIA 9 including Interstates 5 and 405, and State

Routes 18, 167 and 516. The study paved the way for increased development in the lower portion of WRIA 9 and nearshore tributary sub-basins (KCPC, 1957). Also, highway access to major industrial development encouraged residential development outside of the core cities.

Shorelands Development

During the 1917-1970 period, most of the development and bulkheading along the WRIA 9 shoreline occurred. This was driven by Washington State selling tidelands to private landowners and landowners protecting the land from erosion. Equally important to transportation, the Port of Seattle, the fifth largest port in the United States, requires dredging of the Duwamish River, promotes heavy shoreline development, and creates potential for exotic species introduction.

Economic Growth

In 1954, the City of Seattle, King County, and the Port of Seattle released the "Development Plan for the Duwamish and Lower Green River." This plan recommended that a large amount of land be converted from farmland to industrial uses. The Development Plan found that "the basic requirements for industrial development either exist or can be developed" in the Duwamish Estuary and Lower Green River Sub-watersheds. At the time, this area seemed to be the logical area to place more than 70 percent of Seattle's expected industrial growth due to the proximity of existing railroad lines and proposed highways. The Development Plan recommended construction of the Howard Hanson Dam to control flooding and expanded dredging and filling of the estuary. It further proposed increasing the industrial area by more than two and a half times from 1,500 acres to 4,000 acres (DGRJSB, 1954).

Recognizing the need for an effective means of guiding and coordinating the physical development of King County, the County Commissioners in June 1959, initiated a reorganization of the County Planning Agency and provided the necessary budget to develop a modern planning program. By 1964, a Comprehensive Plan was prepared under the requirements of the State Planning Enabling Act (RCW 36.70). This initial plan was designed to serve a projected 1985 population of about 1.6 million people within the entire County. The objective of the plan was to "assure the highest degree of public health, safety, and general welfare" while not "unduly jeopardizing the rights of the individual" (KCPD, 1964).

The policy construct of the 1964 King County Comprehensive Plan was to direct growth within the County to predominantly occur in the "Urban Area" outside the City of Seattle. The plan expected that the population of Seattle would increase slightly over its 1960 population of 557,100 persons while the County outside Seattle was expected to reach nearly a million people -- nearly triple its 1960 population. The rest of the County, or that area outside the Urban Area, was expected to grow from 28,700 in 1960 to 73,000 in 1985 (KCPD, 1964). As the population of the County increased, the density of population was expected to increase. Gross density (persons per total acres) for the whole County was expected to increase from 0.68 to 1.21 persons per acre; in Seattle, from 9.84 to 10.33 persons per acre; in the King County Urban Area outside Seattle from 1.17 to 5.34 persons per acre; and in King County outside the Urban Area from 0.3 to 0.7 persons per acre.

ECONOMIC DEVELOPMENT LAND USES & POPULATION CHANGE—1917-1970

From 1910 to 1930, timber production peaked in the Middle and Upper Green River Sub-watersheds. The Great Depression slowed this production beginning in 1930. Coal production peaked in 1918 following earlier coal finds in Renton and Black Diamond. This coal production later decreased as alternative energy sources were found, and sand and gravel production became more important as a result of the increased demand for industrial, residential, and road development (Fuerstenberg, 1999).

Between 1930 and 1960, the Puget Sound Region, consisting of King, Pierce, Snohomish, and Kitsap Counties, was one of the fastest growing areas of the State. The population of the region doubled during that time period, growing from 737,000 people to more than 1.5 million. Most of this growth occurred in the 1940s with the stepping up of defense production. Due to high birth rates and continued defense production, this growth continued throughout the 1950s but at a reduced rate. King County's growth during this period mirrored that of the region. Between 1930 and 1960, the population of King County increased from 464,000 to 935,000, most of which occurred between 1940 and 1950 (KCPD, 1964).

One area in particular experienced a dramatic increase in urbanization. The prime farmlands of the Lower Green River valley from Auburn to Tukwila was converted to warehouses, malls, and industry due to the proximity of roadway systems, reduced threat of flooding, and the flat, easily developable land. Between 1965 and 1989, agricultural land uses in the Lower Green Sub-watershed dropped by 70 percent (from 11,172 acres to 3,447 acres) while industrial and warehouse areas increased by more than 500 percent (from 1,226 acres to 6,559 acres) (Scarey, 1994). The areas of Big Soos Creek, Covington Creek, and the plateau west of the Green River valley also experienced rapid suburban residential development during this time period (USACE, 1997).

1970-2000: HEIGHTENED REGIONAL PLANNING & ENVIRONMENTAL AWAKENING

ENVIRONMENTAL PROTECTION POLICY—1970-2000

Environmental Concerns Establish a Regulatory Framework

The federal Environmental Protection Agency (EPA) was established in 1970 to respond to nationwide concerns about environmental damage. The National Environmental Protection Act (NEPA), the first official federal action of 1970, established a national policy to weigh human land use activities with environmental concerns. Environmental impact statements were required for new development, alternatives were evaluated, and mitigation required for environmental damages (Lewis, 1985).

The State Environmental Protection Act (SEPA) was adopted in 1971 (RCW 43.21c). It sought to strike a balance between development and environmental protection. SEPA aimed to avoid negative environmental impacts by requiring land use projects to consider impacts of various alternative project designs and mitigate for environmental damages. The passage of SEPA ushered in an era that saw a policy shift toward environmental considerations on both the state and local level that affected land use in WRIA 9.

Shorelands Protection

The federal Coastal Zone Management Act (CZMA) was enacted in 1972 to preserve, protect, and restore the nation's coastal zone resources. The CZMA established a unique state-federal partnership designed to encourage and assist states in developing and implementing management programs to achieve a variety of goals, including the achievement of "wise use of the land and water resources of the coastal zone" (Good et. al., 1998).

Washington State was the first state in the nation to establish a federally approved coastal zone management program (CZMA). The State Shoreline Management Act (SMA) (RCW 90.58.020) is the primary means by which the state meets its CZMA requirements. The SMA states that shorelines should be managed to:

- Foster all reasonable and appropriate uses, particularly "water dependent uses;"
- Provide the public the opportunity to enjoy the physical and aesthetic qualities of natural shorelines; and
- Ensure uses are designed and conducted in a manner to minimize damage to the ecology and environment of the shoreline area and any interference with the public's use of the water.

The SMA is implemented and enforced by local governments in the form of Shoreline Master Programs (SMPs) and the State Department of Ecology serves in a support and review capacity to assist and ensure that local governments comply with the act (Broadhurst, 1998).

Specific uses and activities within the shoreline zone are governed/regulated by local SMPs, including aquaculture, mining, commercial development, industrial development, recreation, marinas, and shoreline modifications such as dredging, landfills, piers, and bulkheads. However, because the SMA is explicitly designed to balance public shoreline uses with the rights of private property owners, a number of activities within the shorezone are exempt from the mitigation and other requirements set forth in the SMA and local SMPs. These include:

- Developments having a fair market value less than $2,500;
- Maintenance of existing structures;
- Construction of single family bulkheads; and
- Construction of single family residences.

Approximately 90 percent of Puget Sound's shorelines are in private ownership. Single family residences are exempt from permitting requirements in the Shoreline Management Act and it is unclear if these shorelines are being afforded the necessary level of protection (Broadhurst, 1998). In November 2000 (too late to be reviewed for this document), the State finished reviewing and updating the Shoreline Master Program Guidelines to reflect best available science regarding the functions and values of shoreline resources.

Farmlands Preservation

Recognizing that an unintended consequence of earlier flood control policies in the Green/Duwamish River Watershed was the rapid conversion of agricultural land to other, more intensive land uses, the 1964 Comprehensive Plan included “Land Used for Agriculture” as an element in its definition of Open Space and identified policies to ensure that these areas were retained within the County (KCPD, 1964). The County continued to categorize its agricultural lands and emphasize the need to protect them and in 1977 adopted Ordinance No. 3064 that established seven Agricultural Districts and designated specific areas within them as “Agricultural Lands of County Significance.”

King County voters adopted the Farmlands Preservation Act in 1979, which created the Farmland Preservation Program. This ballot measure allowed the County to purchase $50 million worth of development rights on agricultural lands at fair market value in return for a guarantee that those lands would remain in agricultural use. This policy has helped slow the conversion of agricultural lands to other uses, with approximately 2,900 acres of farmlands in the WRIA 9 preserved in the 1980s and 1990s. Nearly 10,000 acres in WRIA 9 are in the Agriculture Production District, which gives farmers tax breaks for farming. The Farmland Preservation Program does, however, limit some protection and restoration of fish and wildlife habitat on parcels under the Program, since the covenants placed on these properties prohibit decreasing their agricultural capability to support non-agricultural uses. In 1985, the County took further action to protect farmland when it established agricultural land use policies and zoning regulations.

Growth Management

The environmental awakening of the 1970s coincided with an economic downturn in the Puget Sound region. Despite the economic downturn, the growth and development predicted by the 1964 King County Comprehensive Plan proved to be real. This growth presented many unanticipated growth-related problems, including energy shortages, congested highways, air pollution, disappearing farmlands, and rising cost for housing and public services. In response, King County established a growth management program in 1978 to reexamine and revise the 1964 document. The King County population increased 9.5 percent between 1970 and 1980. Forecasts at that time predicted the population to increase 9.3 percent between 1980 and 1990, then increase 19.1 percent between 1990 and 2000. The 2000 forecast population was 1,638,920 people, or nearly 30 percent greater than the 1980 population of 1,269,749.

The 1985 King County Comprehensive Plan established a pattern of countywide growth development, which would encourage population growth in areas with the infrastructure and facilities to support growth, the “Urban Growth Area” (UGA), while discouraging growth in areas designated as the “Rural Area” and “Resource Lands and Industries.” In the Rural Area, low-density residential development was encouraged to maintain rural character and promote small-scale farming and forestry. The Rural Area was also to provide a buffer to Resource Lands from incompatible land uses and rural service levels were to be maintained. Resource Lands and Industries designations were intended to conserve farmlands, forestlands, and mineral resources, and to encourage and promote their productive management by resource industries (KCPD, 1985).

To address environmental quality issues presented by growth, the 1985 Comprehensive Plan established policies to protect the quality of the natural environment through land use plans, regulations, and incentive programs and to encourage the retention of open space. One policy called for the following areas of the County to remain undeveloped:

- Floodways of 100-year floodplains;
- Slopes with a grade of 40 percent or more;
- Severe landslide hazard areas;
- Wetlands rated as unique/outstanding or significant; and
- Coal mine hazard areas.

These natural features were designated as Open Space and described, classified, and mapped in the Sensitive Areas Map Folio and the Inventory of King County Wetlands. These reports, along with all other available data, were the basis for specific land use regulations for "environmentally sensitive areas" (KCPD, 1985).

Washington State responded to problems associated with statewide growth by adopting the State Growth Management Act (GMA) of 1990 (RCW 36.70A), which was the first critical step in the development of rational policies to sustain growth in Washington. For the first time in the State's history, all urban counties and their cities were required to develop and adopt comprehensive plans and regulations to implement these plans. To ensure comparable planning efforts, the GMA required that comprehensive plans address specific issues including (but not limited to) land use, transportation, housing, facilities and services, utilities, natural environment, and economic development. To achieve coordinated planning efforts, the GMA further required that counties and cities develop a set of framework policies to guide development of each jurisdiction's comprehensive plan. The King County Countywide Planning Policies define the countywide vision and establish the parameters for comprehensive plans of all the cities and the County. Implementing regulations were required that must be consistent with comprehensive plans (KCDDES, 1994). King County adopted a new Comprehensive Plan in 1994 to respond to the GMA. All of the cities followed suit between 1994 and the present.

The Countywide Planning Policies call for consistent approaches to protect critical areas (also known as environmentally sensitive areas) and directed the majority of future growth to within the Urban Growth Area of the western third of the County. In so doing, the intent was to limit urban sprawl, enhance open space, protect rural areas, and more efficiently use human services, transportation, and utilities. Within the Urban Growth Area, the Countywide Planning Policies designated "Urban Centers" within the boundaries of several cities. The 14 Urban Centers are areas in which concentrated employment and housing is to be achieved. The Urban Centers are to be directly serviced by high-capacity public transit. They contain a wide variety of land uses including retail, recreational, cultural and public facilities, parks, and open spaces. The policy construct is to establish well-designed, highly livable Urban Centers that will encourage people to work and live there. If successful, this will contribute to achieving the growth management goal of concentrating infrastructure investments and preventing urban sprawl and environmental degradation. Six of the 14 designated Urban Centers are located in WRIA 9. They are the central business districts of Seattle, Renton, SeaTac, Kent, and Tukwila, and the First Hill/Capital Hill area of Seattle (KCDDES, 1994).

One of the basic goals of the Growth Management Act is to encourage affordable housing. The GMA directs all the jurisdictions' comprehensive plans to make adequate provisions for existing and projected housing needs of all economic segments of the communities. The Countywide Planning Policies call for each jurisdiction to specify the range and amount of housing needed for various income groups. A key component of meeting this housing objective is by providing sufficient land for housing in communities throughout the County. In particular, land must be available for affordable housing types: higher density single-family housing; multifamily housing; manufactured housing; accessory apartments; and mixed-use developments. All of these housing types provide opportunities for development of affordable housing (KCDDES, 1994). Efforts to provide sufficient land, infrastructure, and reduced development costs for affordable housing is difficult to balance with the need to establish and maintain an Urban Growth Area sized to reduce urban sprawl. This balance remains difficult as costs associated with new housing construction and the demand for housing in the Puget Sound region grow.

The Urban Growth Area created by the Countywide Planning Policies was established to provide sufficient land to accommodate the expected number of households through 2012 (20-year planning horizon). Ensuring that there was capacity to accommodate projected household growth was a key element of growth management planning efforts throughout the County in the early to mid 1990s (KCDDES, 1994B and KCCPPBP, 2000).

Land use indicators of the Countywide Planning Policies Benchmark Program show that there is ample capacity within the existing Countywide Urban Growth Area to accommodate the estimated remaining number of targeted households and jobs by 2012 (170 to 198 percent capacity of remaining target). In WRIA 9, the capacity remaining in the Urban Growth Area ranges from 95 percent in Tukwila to over 200 percent in Renton, Kent, and Seattle. The Countywide Rural Area has over 500 percent capacity to accommodate household and job targets (2000 King County Benchmark Report).

These land use indicators suggest that there is no need to increase the size of the Urban Growth Area to accommodate projected growth and to achieve affordable housing goals. This information also suggests that the growth capacity in the Rural Area is not needed. Indeed, the amount of growth in the Rural area has decreased from 1994 to 1999 from 11 percent to five percent of the total amount of Countywide household growth; the amount of growth in the Urban Growth Area increased from 88 percent in 1994 to 95 percent in 1999. Another trend is growth in urban core areas versus the outer portions of the Urban Growth Area. Urban core areas steadily increased from 47 percent of the total amount of household growth to 62 percent from 1994 to 1999. During this same period of time, the amount of growth in the outer fringe areas of the UGA decreased from 42 percent to 33 percent of the total Countywide household growth (2000 King County Annual Growth Report).

Endangered Species Protection

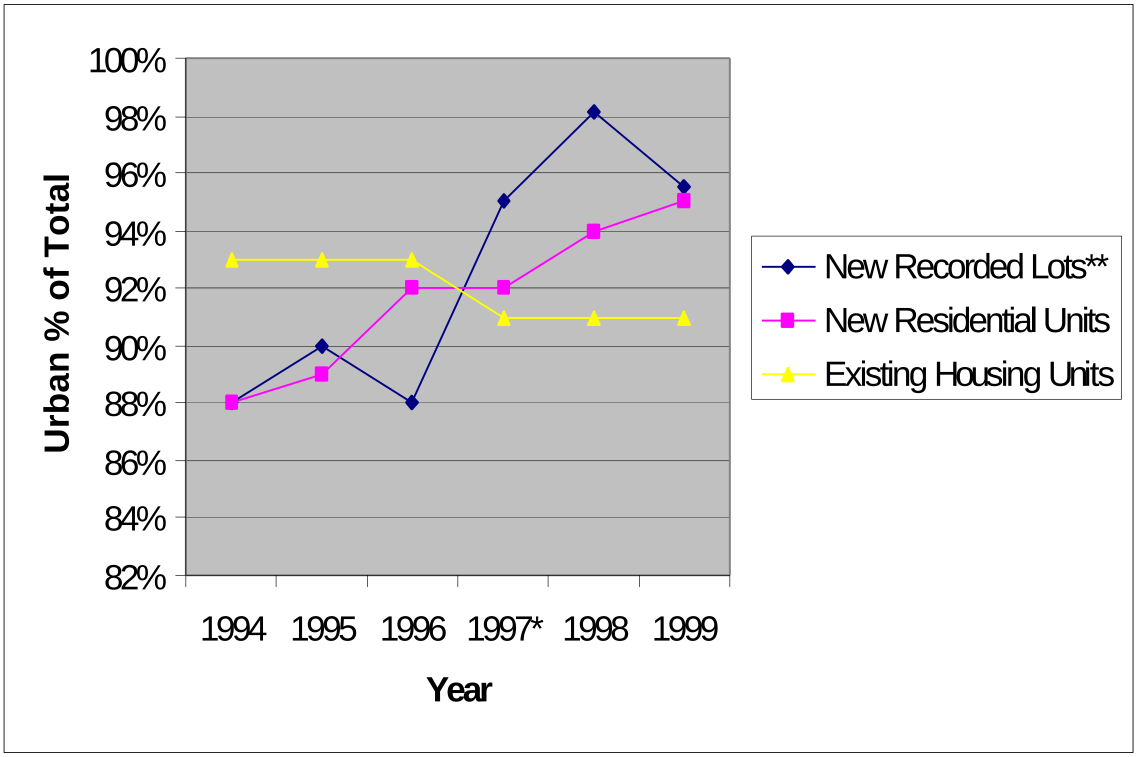
The latest policy to affect land uses in WRIA 9 is the Endangered Species Act (ESA) of 1973, triggered locally by the 1999 listing of chinook and bull trout as threatened species. The purpose of the Endangered Species Act is "to provide a means whereby the ecosystems upon which endangered and threatened species depend may be conserved, and to provide a program for the conservation of these species." The ESA prohibits the "take" of any "endangered" or "threatened" species or the degradation of habitat critical to these species. The ESA involves a process of species listings (Section 4), definition of "take" (Section 4d), federal agency consultations to avoid "take" (Section 7), prohibition of "take" (Section 9) and a citizen suit provision (Section 11). The Act may affect land use activities if the land use is construed as a "take." It is unclear how the ESA will be implemented in the area. However, land use activities are one of many human activities that may be restricted in order to protect salmon populations. The effect of ESA on GMA will play out over the next 10-20 years and may have new impacts on land use in WRIA 9 (West Group, 1998).

LAND USES AND ENVIRONMENTAL PROTECTION—1970-2000

As the Puget Sound population centers continued to expand from the 1970s through the 1990s, WRIA 9 became increasingly urbanized in the Nearshore, Green/Duwamish Estuary, Lower Green, and Middle Green River sub-watersheds. With the inception of the Washington State Growth Management Act in 1990, local governments have tried to slow growth in the rural area. Figure LU-1 and LU-2 show the King County development trends from 1994 to 1999. (Figures LU-1 and LU-2 were developed from Table LU-6 in the Appendix.) Figure LU-1 shows that from 1994 to 1999, or following implementation of the GMA, there has been a dramatic increase in the amount of residential development in the Urban Growth Area. Figure LU-2, shows that there has been a corresponding decrease in the amount of residential development in the Rural Area. Only eight percent of the permits issued by King County in 1997 were in the Rural Area, versus 20 percent for the Puget Sound region as a whole (PSCR, 1998).

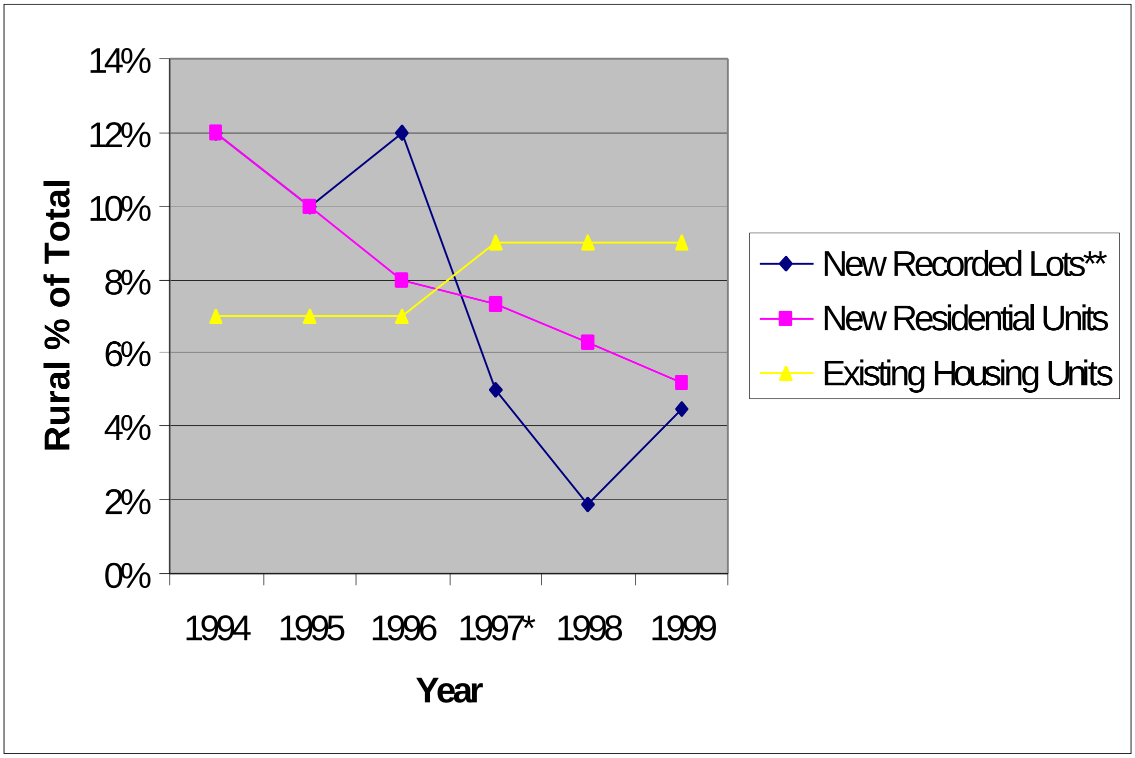
Despite this trend, which is driven by the successful implementation of growth management plans by all jurisdictions of the County, the Puget Sound Regional Council (PSRC) found that a 19 percent increase in population between 1980 and 1990 was also accompanied by a 37 percent increase in developed land (PSRC, 1998).

Figure LU-1. King County Land Development Indicators -Urban (KCORPP, 2000).



* Data not comparable in previous years due to a change in measuring existing housing units.
** Does not include short plats.

Figure LU-2. King County Land Development Indicators - Rural (KCORPP, 2000).



* Data not comparable in previous years due to a change in measuring existing housing units.
** Does not include short plats.

Estimates using PSRC data show that the population of WRIA 9 is currently approximately 563,980. About 89 percent live in the Urban Growth Area and 11 percent live in the Rural Area or Resource Lands (derived from 2000 PSRC data). Additional population information is presented later in this chapter.

PRESENT-DAY LAND COVER AND DESIGNATED LAND USE

The land area of WRIA 9 is 568-square-mile area. Thirty percent of the WRIA is within the Urban Growth Area (UGA). The land use/land cover statistics (found in the tables and maps of the text and Appendix) are categorized from 1995 King County land cover data. Designated land use statistics (found in the tables and maps of the text and Appendix) are categorized from recent Puget Sound Regional Council data that summarized current comprehensive plans. Figure LU-4 and figure LU-5 show land cover and designated land use mapped, respectively. The maps show the increasing urbanization within the UGA and how planning can drive these types of development.

Table LU-3 summarizes some of the information found in tables LU-7 through LU-18 in the Appendix. Each sub-watershed is listed below with the designated land use (from comprehensive plans) and percent land area found in the UGA. The land use designation is vastly different from sub-watershed to sub-watershed. WRIA 9 has a variety of land uses from forestry to agriculture and from residential to industrial.

Table LU-3. Designated Land Uses in WRIA 9 (derived from 2000 PSRC data).						
Land Use Designations	**% of Upper Green River Subwatershed**	**% of Middle Green River Subwatershed**	**% of Lower Green River Subwatershed**	**% of Green/Duwamish Estuary Subwatershed**	**% of Nearshore Subwatershed**	**% of Vashon Is. Subwatershed**
Agriculture		11	5			4
Commercial		1	10	1	6	
Commercial Forestry	100	26				
Industrial		1	17	44	10	
Mixed Use		1	5	2	4	
Residential		50	50	39	68	92
Mineral Resources		2				1
Other		3	7	10	4	
Parks & Open Space		5	6	4	8	3
% of Sub-watershed in UGA	**0**	**22**	**100**	**100**	**100**	**0**

UPPER GREEN RIVER SUB-WATERSHED

The Upper Green River Sub-watershed is nearly 100 percent utilized for commercial forestry. No permanent settlements currently exist in this sub-watershed but human development is characterized by large forestry operations, a flood control dam and reservoir, a water supply diversion dam providing water for the City of Tacoma, the Burlington Northern Santa Fe railroad, and a major electric utility transmission line (USACE, 1997). Public access is restricted in some areas. There are seven principal land owners in the sub-watershed including U.S. Forest Service, Plum Creek, Weyerhaeuser, Guistina Resources, Washington Department of Natural Resources, Tacoma Public Utilities, and Burlington Northern Santa Fe. None of the Upper Green River Sub-watershed is in the UGA. (See Tables LU9 & LU10 in Appendix)

MIDDLE GREEN RIVER SUB-WATERSHED

The Middle Green River Sub-watershed is roughly split between residential development (50 percent) and a mix of commercial forestry (27 percent) and agriculture (12 percent). Most of the upper portion is rural residential, forestry, and agriculture while cities and unincorporated urban areas dominate the lower portion of this sub-watershed. It includes all or portions of the cities of Auburn, Black Diamond, Covington, Enumclaw, Kent, and Maple Valley. Twenty-two percent of the Middle Green Sub-watershed is in the UGA. (See Tables LU11 & LU12 in Appendix).

LOWER GREEN RIVER SUB-WATERSHED

The Lower Green Sub-watershed consists of residential development (50 percent), industrial development (17 percent), and commercial development (10 percent). Most of the land area is incorporated in the cities of Algona, Auburn, Federal Way, Kent, Renton, SeaTac, and Tukwila (representing four of the 14 Urban Centers). In this sub-watershed, it is estimated that 80 percent of the Green River from river mile (RM) 17 to river mile (RM) 33 has been leveed or revetted on at least one bank for flood protection (Perkins, 1993). Most of the floodplain has been filled, drained and developed. About 5 percent is in the County's Agricultural Production District. Nearly 100 percent of the Lower Green River Sub-watershed is in the UGA. (See Tables LU13 & LU14 in Appendix)

GREEN/DUWAMISH ESTUARY SUB-WATERSHED

The Green/Duwamish Estuary Sub-watershed is characterized by industrial development (43 percent) and residential development (39 percent). The cities of Seattle and Tukwila, operations of the Port of Seattle (the fifth largest port in the U.S.), and the region's largest industrial complexes are in this sub-watershed. In the lower portion of the estuary, the loss of estuarine and riparian habitat has been extensive. The estuary shoreline has been dramatically altered: 21,000 feet have been lost due to straitening of the channel and 53,000 feet have been filled and developed. Only 19,000 feet of vegetated riparian shoreline remains. The once extensive 3,850 acres of tidal mudflats, marshes, and swamps have been reduced to only 45 acres. Ninety-seven percent of the estuary has been filled (USACE, 1997). This entire sub-watershed is in the UGA. (See Tables LU15 & LU16 in Appendix)

NEARSHORE SUB-WATERSHED

The Nearshore Sub-watershed has been heavily altered and currently consists of residential (68 percent) and industrial (10 percent) land uses. This portion of the Puget Sound coastline has one of the largest coastal populations in the state including all or portions of the cities of Burien, Des Moines, Federal Way, Kent, Normandy Park, SeaTac, and Seattle. In the center of this sub-watershed is one of the region's largest public facilities, SeaTac International Airport. The Nearshore Sub-watershed has one of the highest degrees of shoreline modification in the state at nearly 80 percent. Most shoreline modification such as seawalls and bulkheads were placed to protect residential development from erosion (WSDNR, 1998). This entire sub-watershed is in the UGA. (See Tables LU17 & LU18 in Appendix)

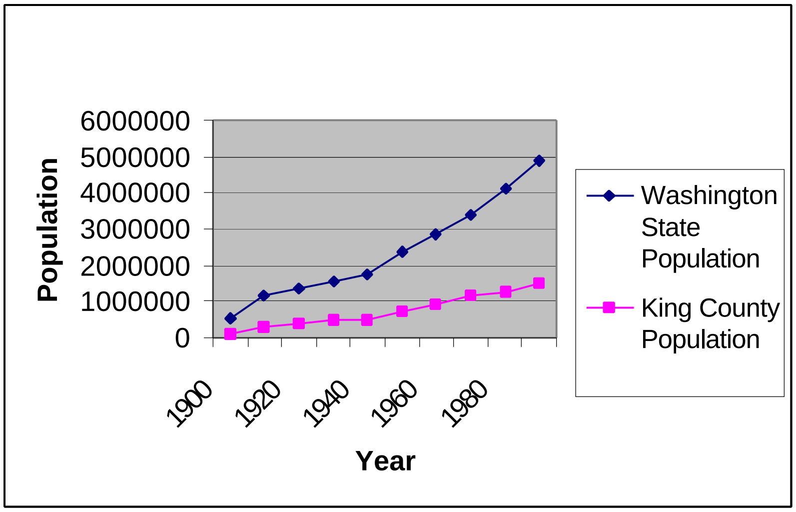
VASHON SUB-WATERSHED

The Vashon Sub-watershed has remained far less developed than much of the surrounding area due to its isolation and finite ground water supply. Regardless, the island is designated primarily for rural residential (92 percent) land uses. Along with the residential land uses there are some agriculture and mining operations on the island. A variety of rare and pristine habitat areas are found here including two salt marshes and two of the last remaining undisturbed salmon streams in King County. Two-thirds of the island is still currently forested (Munday, 1999). None of the Vashon Sub-watershed is in the UGA. (See Tables LU19 & LU20 in Appendix).

POPULATION GROWTH

Population has increased dramatically since the beginning of the 19th century. In the early 20th century, the region experienced a dramatic increase in population predominantly in the urban areas such as Seattle and the other watershed cities. As the Puget Sound population centers continued to expand through the 1970s, 1980s, and 1990s, WRIA 9 has experienced increasing urbanization throughout its Urban Growth Area. The Puget Sound Regional Council has found that for every 1 percent increase in population growth there is a corresponding 2 percent or higher increase in developed land (PSRC, 1998). Figure LU-3 shows population growth in Washington State and King County since 1900.

Figure LU-3: Population Growth 1900-1990 (U.S. Census Bureau, 2000).



In 1999, population in WRIA 9 was estimated at 563,980 (adapted from PSRC data, 2000). Eighty-nine percent of this population resides within the UGA. Table LU-4 shows the population numbers for the sub-watersheds. The Nearshore Sub-watershed has the largest population.

Table LU-4. Sub-watershed Population (derived form 2000 PSRC data).

Sub-watershed	Total Population	% of Total Watershed
Upper Green River	128	0
Middle Green River	112,130	20
Lower Green River	153,755	27
Green/Duwamish Estuary	57,647	10
Nearshore	230,718	41
Vashon	9,602	2

Table LU-5 provides data on the numbers of residents in cities wholly or partially within WRIA 9 in 1990 and 1996. Except for the City of SeaTac, the populations of all the cities in WRIA 9 grew between 1990 and 1996. The cities of Algona, Black Diamond, Enumclaw, and Kent experienced the greatest growth, with an average annual growth rate of 2 percent or higher, due to both annexations and new residential development.

Table L-U5. Population Distribution in the Green/Duwamish River Basin (numbers are calculated by jurisdiction and may fall out of the WRIA boundaries (U.S. Census Bureau, 2000).				
			Average Annual Growth Rate	
Jurisdiction	1990a	1996b	Percent per Year	Relative Rate
Algona	1,694	2,135	4.34	High growth
Auburn	33,650	36,393	1.36	Moderate growth
Black Diamond	1,422	1,967	6.39	High growth
Burien	25,507	26,882	0.90	Low growth
Covington	24,321	ND	ND	ND
Des Moines	17,283	17,811	0.51	Low growth
Enumclaw	7,227	9,500	5.09	High growth
Federal Way	67,535	68,088	0.14	Low growth
Kent	37,960	42,700	2.08	High growth
Maple Valley	1,211	ND	ND	ND
Normandy Park	6,794	6,846	0.13	Low growth
Renton	41,688	45,155	1.39	Moderate growth
SeaTac	22,760	22,723	-0.03	Negative growth
Seattle	516,259	524,704	0.27	Low growth
Tukwila	14,506	14,556	0.06	Low growth
King County (as a whole)	1,507,319	1,598,707	1.01	Moderate growth
Washington State	4,866,692	5,433,068	1.94	Moderate growth

Notes:
ND = no data available.
a Census Bureau data as of April 1, 1990.
b Census Bureau estimate data as of March 12, 1999.

LIST OF TABLES

Table L-U1. Overview of possible impacts of human land use to natural aquatic systems.

Table L-U2:.Chronology of Policies and Events in the WRIA 9: 1790-2000.

Table L-U3. Designated Land Uses in WRIA 9.

Table L-U4:.Sub-watershed Population.

Table L-U5. Population Distribution in the Green/Duwamish River Basin.

[Note: Tables LU-6 through LU-18 are located in the report Appendix.]

Table LU-6. King County Land Development Indicators.

Table LU-7. Current Land Cover/Land Use for the Upper Green Sub-watershed.

Table LU-8. Designated Land Use for the Upper Green Sub-watershed.

Table LU-9. Current Land Cover/Land Use for the Middle Green Sub-watershed.

Table LU10. Designated Land Use for the Middle Green Sub-watershed.

Table LU-11. Current Land Cover/Land Use for the Lower Green Sub-watershed.

Table LU-12. Designated Land Use for the Lower Green Sub-watershed.

Table LU-13. Current Land Cover/Land Use for Green/Duwamish Estuary Sub-watershed.

Table LU-14. Designated Land Use for Green/Duwamish Sub-watershed.

Table LU-15. Current Land Cover/Land Use for the Puget Sound Nearshore Sub-watershed.

Table LU-16. Designated Land Use for Puget Sound Nearshore Sub-watershed.

Table LU-17. Current Land Cover/Land Use for the Vashon Sub-watershed.

Table LU-18. Designated Land Use for the Vashon Sub-watershed.

LIST OF FIGURES

Figure LU-1. King County Land Development Indicators—Urban.

Figure LU-2. King County Land Development Indicators—Rural.

Figure LU-3. Population Growth 1900-1990.

Figure LU-4.Land Cover/Land Use Map.

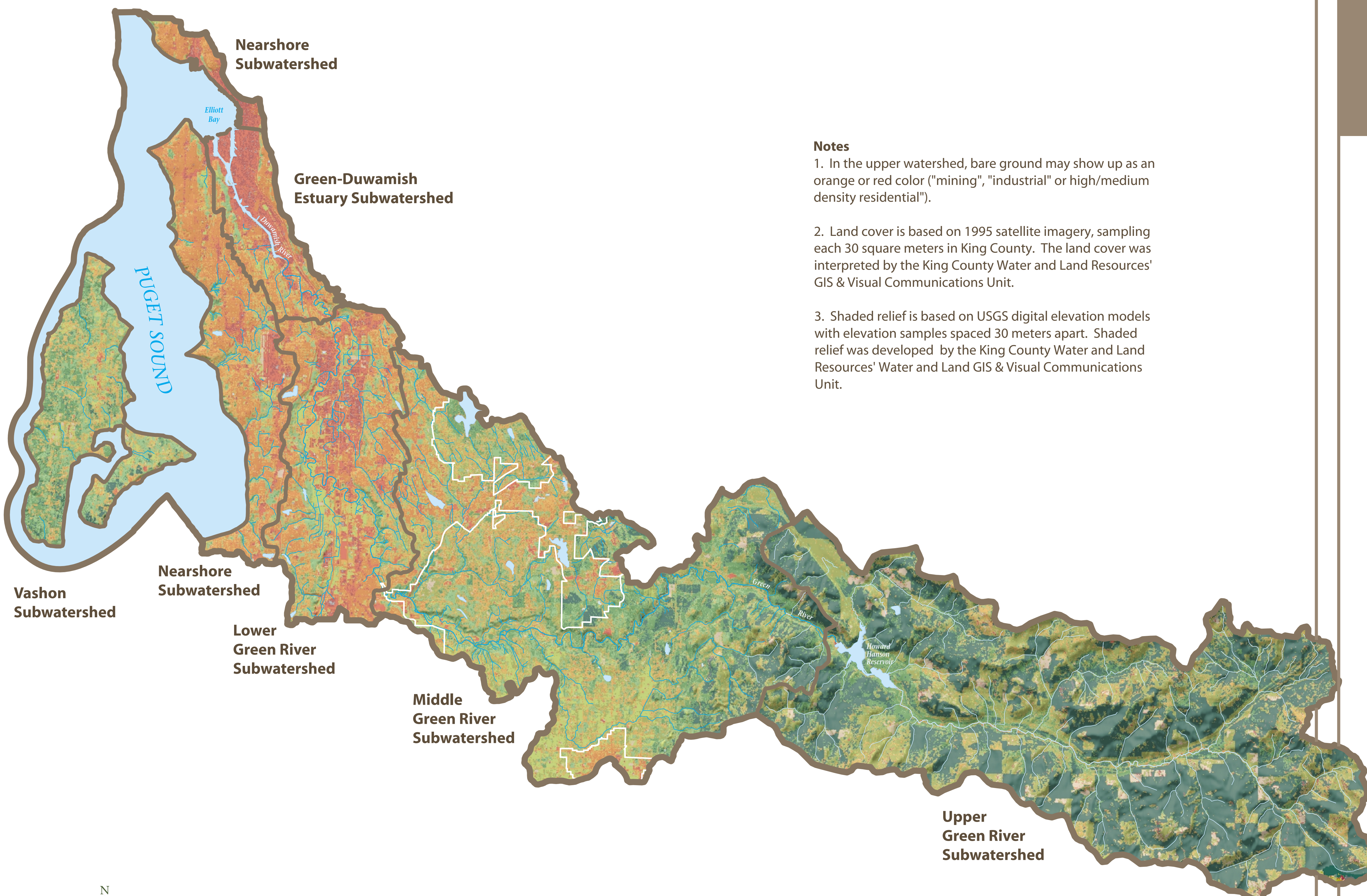
Figure LU-5.Designated Land Use Map.

Figure LU-6.Cities and Major Landowners Map.

Figure LU-4

Land Use and Land Cover Circa 1995

WRIA 9



September 2000

Notes

1. In the upper watershed, bare ground may show up as an orange or red color ("mining", "industrial" or high/medium density residential").

2. Land cover is based on 1995 satellite imagery, sampling each 30 square meters in King County. The land cover was interpreted by the King County Water and Land Resources' GIS & Visual Communications Unit.

3. Shaded relief is based on USGS digital elevation models with elevation samples spaced 30 meters apart. Shaded relief was developed by the King County Water and Land Resources' Water and Land GIS & Visual Communications Unit.

Major Road

River/Stream

FODS Subwatershed Boundary

King County WRIA 9 Boundary

Urban Growth Area Line (as of 12/99)

LAND USE/COVER CATEGORIES

Developed Areas

City, Industrial & Mining

Industrial & Commercial[1]

High Density Residential[1]

Low & Medium Density Residential[1]

Recent Clearcut[1]

Vegetation

Grass

Scrub & Shrub

Deciduous Forest

Mixed Forest

Conifer Forest

Other

Open Water

Bare Rock

Shadow

King County
Department of Natural Resources

File Name: 0009 W9Reco LCOVER.ai
Produced by: GIS & Visual Communications Unit, WLR

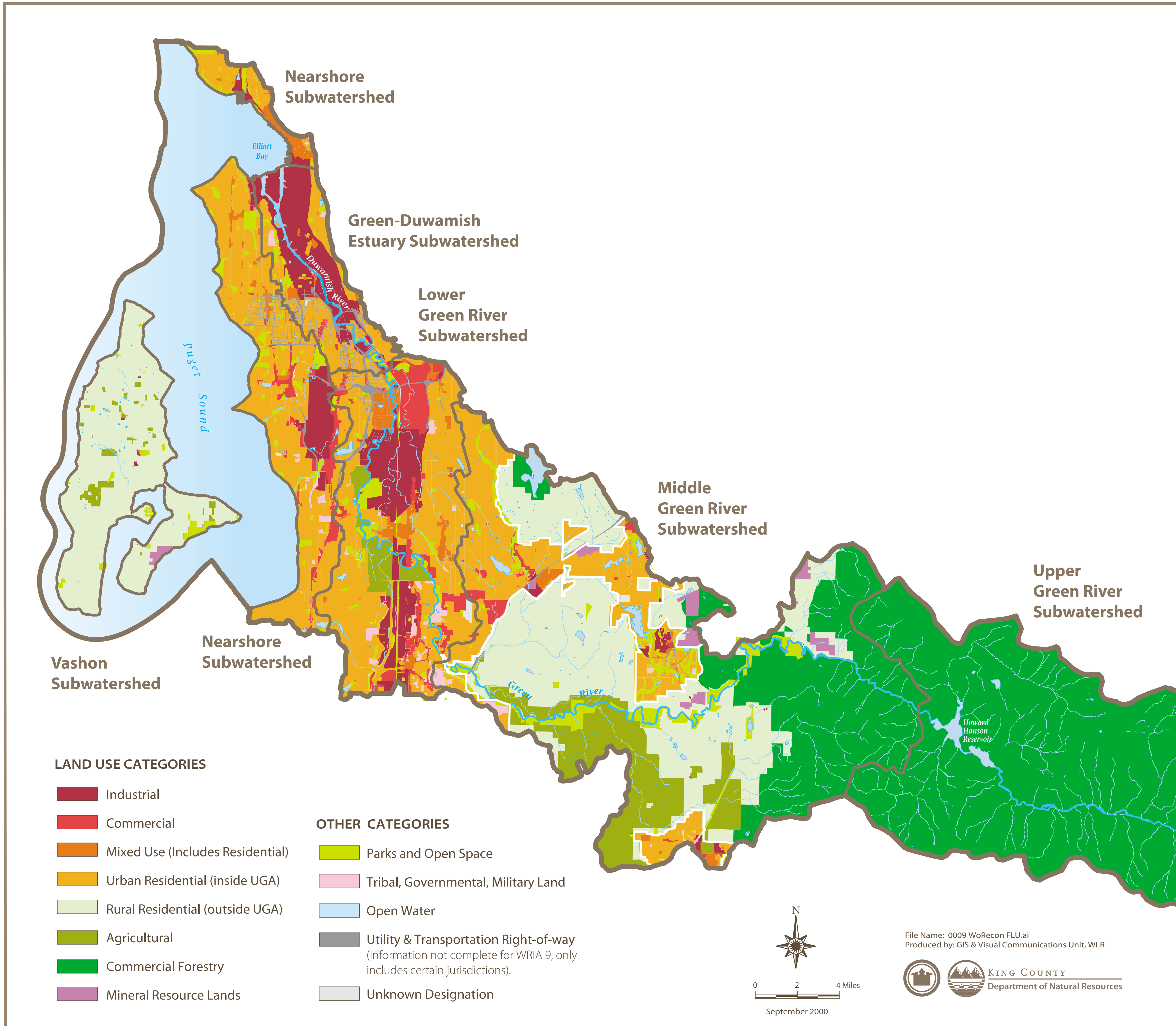


Figure LU-5

Designated Land Use

WRIA 9

River/Stream

FODS Subwatershed Boundary

King County WRIA 9 Boundary

Urban Growth Area Line (as of 12/99)

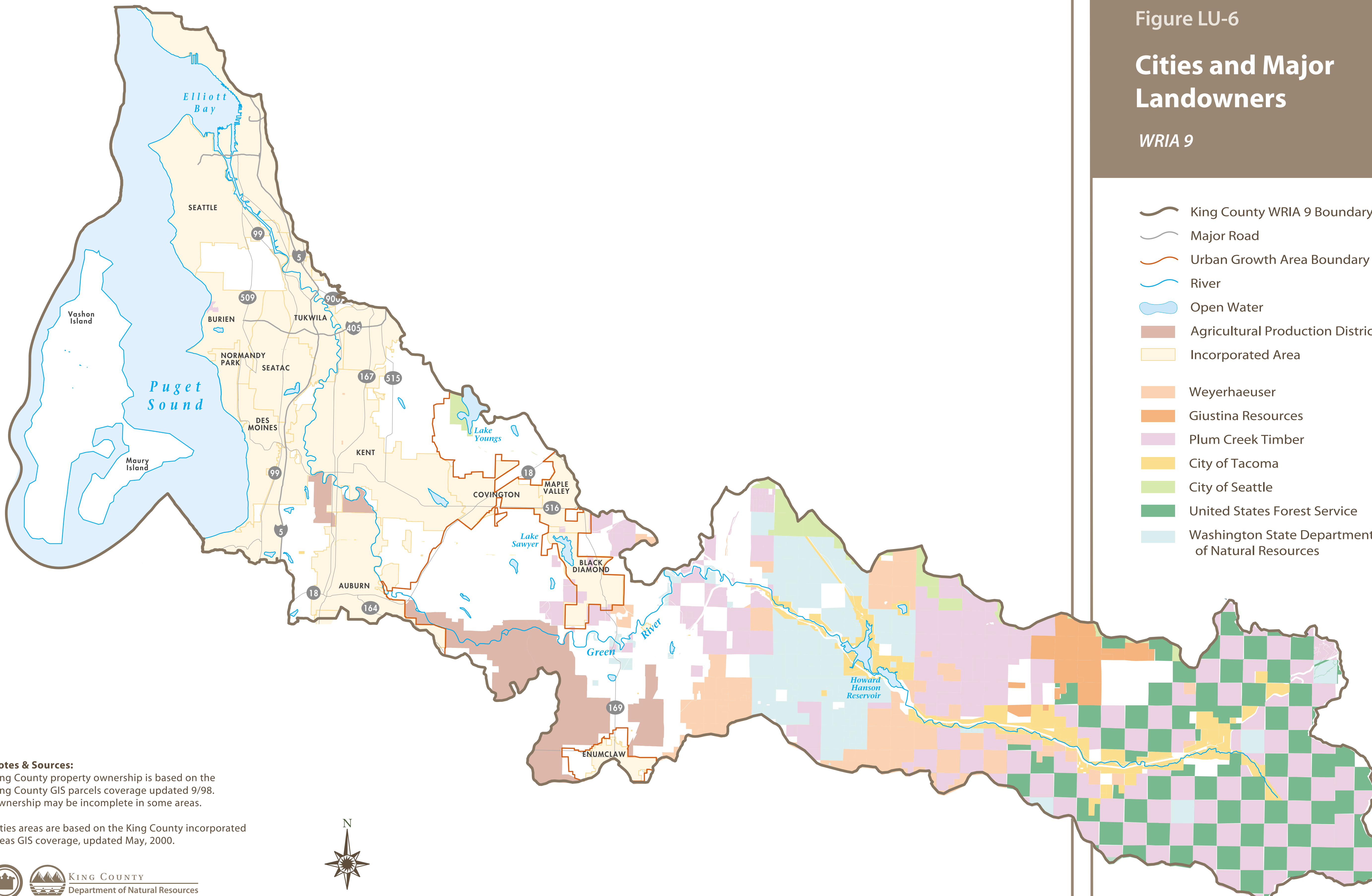
Notes:
Designated land use describes predicted land use based on King County and WRIA 9 cities' comprehensive plans, as compiled and interpreted by the Puget Sound Regional Council in 1999.

Other data sources includethe 1997 KC/DOE Hydrography Project, KC standard WRIA boundaries, and subwatersheds developed for Factors of Decline Study use.

Figure LU-6

Cities and Major Landowners

WRIA 9



- King County WRIA 9 Boundary
- Major Road
- Urban Growth Area Boundary
- River
- Open Water
- Agricultural Production District
- Incorporated Area
- Weyerhaeuser
- Giustina Resources
- Plum Creek Timber
- City of Tacoma
- City of Seattle
- United States Forest Service
- Washington State Department of Natural Resources

Notes & Sources:
King County property ownership is based on the King County GIS parcels coverage updated 9/98. Ownership may be incomplete in some areas.

Cities areas are based on the King County incorporated areas GIS coverage, updated May, 2000.

King County
Department of Natural Resources

File Name: 0011 W9 CityMajorLand.ai
Produced by: GIS & Visual Communications Unit, WLR WGC/LP

0 2 4 Miles

August 2000

1.2 WATER QUALITY

1.2 WATER QUALITY

EXECUTIVE SUMMARY

This chapter provides an assessment of the water quality conditions in the Green/Duwamish watershed from existing water quality reports and from analysis of water quality data collected during the past four years (1996-1999) by the King County Streams Monitoring Program, the Muckleshoot Indian Tribe, and the City of Tacoma. The water quality data were compared to Washington State water quality standards (WAC 173-201A), EPA water quality criteria and appropriate toxicity screening thresholds to assess potential for biological significance. Where possible and when data or studies are available, water quality trends are examined and acute/chronic concentrations are specifically related to conditions that are known to be or may be a factor of decline for salmonids. Available aquatic insect data were also evaluated as a measure of the aquatic ecosystem condition of selected streams. Finally, data gaps are identified for potential future investigations.

The analysis for this report divides the Green/Duwamish basin into four subbasins on the mainstem (Upper, Middle and Lower Green River, and the Duwamish River) and five tributaries (Crisp, Newaukum, Soos, and Mill (Hill) creeks, and the Black (Springbrook) River). The state water quality standards classify the water bodies in this basin as follows: (1) Class B (fair) – Duwamish River; (2) Class A (good) – lower and middle Green River up to river mile (RM) 42.3, Crisp, Newaukum, Soos, and Mill creeks, and the Black River; and (3) Class AA (extraordinary) – middle Green River, from RM 42.3 to the headwaters.

Numerous stream systems throughout the Green/Duwamish watershed are listed on the State's 1998 303(d) list of impaired water bodies. Section 303(d) of the Clean Water Act requires Washington State to identify those water bodies that do not meet water quality standards. The State is then responsible for prioritizing the list and developing Total Maximum Daily Loads (TMDLs) for every water body and pollutant on the list. Some segments are also listed for sediments and tissues, but they are beyond the scope of this report. In the Green/Duwamish watershed, water body segments have been listed for failing to meet water quality standards for one or more of the following parameters: fecal coliform, temperature, dissolved oxygen (DO), pH, ammonia, and metals (cadmium, chromium, copper, mercury, and zinc).

GENERALIZED WATER QUALITY CONDITIONS

Water quality in the Green River and its tributaries varies widely depending on location in the watershed, intensity of land use (level of urbanization), and human activities (King County 1989). The upper Green River watershed is mostly forested and has been minimally altered by human activities (with the exception of construction of the Howard Hanson and Tacoma Diversion dams and logging activities), and thus generally has the best water quality. The middle Green River is dominated by agricultural land use, mixed forest, and rural residential development, and generally still exhibits fairly good water quality conditions. The lower Green River and Duwamish River are the most urbanized and industrialized portions of the watershed and generally have the most degraded water quality conditions in the mainstem.

Of the tributaries assessed, water quality is also closely linked to the level of urbanization and intensity of land use. Crisp Creek has the best overall water quality and is the least developed of the tributaries assessed. Newaukum Creek, which has extensive agricultural land use, generally has good water quality but suffers from occasional depressions in DO levels. Soos Creek has some of the region's best water quality of the smaller creeks in the urban portion of King County. Mill and Springbrook (Black River) creeks are the most heavily urbanized of the tributaries evaluated in this report and exhibit the most degraded water quality conditions.

KEY FINDINGS

This section summarizes some of the key findings from the water quality assessment of existing conditions and trends (where available) for the mainstem and major tributaries. Tables WQ-E1 and WQ-E2 provide a summary of the projected factors of decline for salmonids by subbasin and parameters, providing a quick reference for areas of concern. The criteria used to determine whether a parameter is a factor of decline for salmonids include comparison with water quality standards and toxicity screening thresholds, and listing on the State's 1998 303(d) list. Factors of decline are rated as probable, possible, unlikely, or unknown on the following basis:

1. **Probable**. Probably a factor that contributes to the decline of salmonids based on frequent small exceedances of water quality standards or less frequent significant exceedances, often combined with 303(d) listing for the water body.

2. **Possible**. Possibly a factor that contributes to the decline of salmonids based on occasional small exceedances of water quality standards, or a 303(d) listing for the water body.

3. **Unlikely**. Unlikely to be a factor that contributes to the decline of salmonids based on infrequent or no exceedances of water quality standards and no 303(d) listing for the water body.

4. **Unknown**. No or insufficient data to make a determination or no water quality standards available for evaluation.

The projected water quality factors of decline represent a preliminary assessment based on the best available information. Several factors may contribute to uncertainty in this assessment. First, because this assessment is made by subbasin, the results are generalized, and thus may not show the potential for substantial variability within a subbasin. Second, the sparse data coverage in several subbasins may result in overlooking impaired water quality conditions in some areas. Finally, the lack of continuous data or information on the duration of exposure may lead to an incorrect determination about whether a given parameter is or is not a factor of decline. The key findings are as follows:

1. Water quality conditions in the Lower Green and Duwamish River have improved from the poor water quality conditions that existed in the 1960s. This is a result of the reduction of municipal and industrial discharges (including higher levels of wastewater treatment and reduction of combined sewer overflows (CSOs)) and the relocation of the south municipal wastewater treatment plant outfall to Puget Sound.

2. There has been a trend towards increasing surface water temperatures in most tributaries in the urban and urbanizing areas of the region over the past 20 years, probably attributable to urbanization and development, including increased runoff from impervious surfaces and loss of riparian vegetation.

3. Temperatures in the mainstem during the summer have peaked between 23 and 24 ^{o} C at stations in the Lower and Middle Green River in studies involving continuous monitoring probes, based on available data. In some years, this is probably of concern for adult chinook migration up the Green River in August and early September. Water temperatures in some tributaries of the Mill (Hill) and Springbrook subbasins have been historically high and are probably of concern for salmonid rearing. Water temperatures during spawning and rearing are also of concern for several Soos Creek tributaries. There are insufficient data and information on the distribution of bull trout in the watershed to assess to what extent localized temperature conditions are a concern for bull trout.

4. Dissolved oxygen (DO) levels are one of the most significant issues for salmonids in the basin. In the mainstem, DO levels in the Duwamish and Lower Green rivers are of concern for salmonid rearing on some occasions. In the mainstem above RM 24 (where most mainstem spawning occurs), DO levels in the Middle Green River are occasionally of concern during incubation. DO for incubation and rearing is a probable factor of decline for salmonids in several tributaries, particularly Springbrook Creek, Mill (Hill)[1] Creek, Soos Creek and Newaukum Creek. The most severe documented DO problem in the basin is in Mill Creek (just north of SR-18).

5. Turbidity and total suspended solids (TSS) are possible factors of decline in terms of water column impacts for the Duwamish River, Lower Green River, Mill Creek and Springbrook Creek. However, no data were available for the duration of exposure, so it is difficult to determine the extent to which TSS is of concern. TSS may be a concern in terms of sedimentation in some areas, but this was outside the scope of this study, and would be better characterized by analysis of sediment deposition or embeddedness.

6. Based on the King County Streams water quality data evaluated from 1996 to 1999, pH, ammonia, and metals are unlikely to be factors of decline for salmonids at the locations analyzed. Ammonia may be a factor of decline in the Mill Creek basin based on data collected between 1990 and 1991 by King County. Metals (cadmium, chromium, copper, mercury, and zinc) may be of concern in Springbrook Creek based on sampling carried out by Ecology and King County (Metro) between 1984 and 1990 that led to its listing on the 303(d) list. It is possible that there are localized areas near stormwater outfalls to smaller tributaries where metals could also be of concern.

7. No data were available to assess to what extent organic chemicals such as pesticides, polycyclic aromatic hydrocarbons (PAHs), and phthalates are a factor of decline for salmonids.

---

[1] Mill Creek (also known as Hill Creek) flows through the City of Auburn and will hereafter be referred to as Mill Creek throughout this report.

8. In the Duwamish Estuary, risks to water column dwelling organisms are minimal; however, there are potential risks to benthic organisms from several chemicals in the sediments, most notably bis(2-ethylhexyl)phthalate, 1,4-dichlorobenzene, mercury, polycyclic aromatic hydrocarbons (PAHs), PCBs, and tributyltin (TBT) (King County, 1999). Risks to the benthic community can potentially translate to risks to salmonids via food-chain transfer (bioaccumulation in prey), reduction in function of immune systems, or from potential toxicity to prey organisms (reduction in available food).

9. Biological monitoring of macroinvertebrates in the Soos Creek basin (1995-98) found highly variable conditions. Five of eight stations monitored had benthic index of biotic integrity (B-IBI) scores in the fair range, two were in the poor range and one station was in the very poor range. Seven stations monitored in 1999, located throughout the mainstem of the Green River all had B-IBI scores in the fair range. Mill (Kent) and Meridian Valley creeks had B-IBI scores in the very poor range.

10. Although aluminum concentrations often exceed the EPA national criterion throughout the watershed, this does not necessarily indicate aluminum is a factor of decline. Measurements of total aluminum include several forms, such as aluminum that is occluded in minerals, clay and sand or is strongly sorbed to particulate matter, that are not toxic or are not likely to become toxic under natural conditions (U.S. EPA 1988). Therefore, this criterion may be overprotective when based on the total recoverable method because the digestion procedure dissolves some aluminum that is not toxic and cannot be converted to a toxic form under natural conditions (U.S. EPA 1988).

Table WQ-E1. Projected water quality factors of decline based on data evaluated in this report.

Parameter Subbasin	Temperature	DO	TSS*	pH	Ammonia	Metals	Pesticides, PAHs, Phthalates
Upper Green	Possible	Unknown	Unlikely	Unknown	Unknown	Unknown	Unknown
Middle Green	Possible	Possible	Unlikely	Unlikely	Unlikely	Unlikely	Unknown
Lower Green	Probable	Possible	Possible	Unlikely	Unlikely	Possible	Unknown
Duwamish	Probable	Possible	Possible	Unlikely	Unlikely	Possible	Unknown
Crisp	Possible	Possible	Unlikely	Unlikely	Unlikely	Unlikely	Unknown
Newaukum	Possible	Probable	Unlikely	Unlikely	Unlikely	Unlikely	Unknown
Soos	Probable	Probable	Unlikely	Unlikely	Unlikely	Unlikely	Unknown
Mill (Hill)	Probable	Probable	Possible	Unlikely	Possible	Unlikely	Unknown
Springbrook (Black R.)	Possible	Probable	Possible	Unlikely	Unlikely	Possible	Unknown

* Due to lack of data on duration for TSS, further investigation is needed for all locations
TBD = To be determined.

Table WQ-E2. Detailed water temperature and dissolved oxygen projected factors of decline[1].					
Parameter	**Temperature**			**Dissolved Oxygen**	
Subbasin	Migration	Rearing	Spawning[2]	Rearing	Incubation[2]
Upper Green [2]	Unlikely	Unlikely	Possible	Unlikely	Unknown
Middle Green	Unlikely	Possible	Possible	Unlikely	Possible
Lower Green	Possible [3]	Probable	N/A	Possible	N/A
Duwamish	Possible [3]	Probable	N/A	Possible	N/A
Crisp Creek	Unlikely	Possible	Possible	Unlikely	Probable
Newaukum	Unknown [4]	Unknown [4]	Possible	Probable	Probable
Soos	Possible [3]	Probable	Probable	Probable	Probable
Hill/Mill	Possible [3]	Probable	Probable	Probable	Probable
Springbrook (Black River)	Unknown [4]	Possible	Possible	Probable	Probable

[1] This evaluation does not include temperature and DO requirements for bull trout.
[2] Proposed spawning and incubation standard only applies from Sept 15 to June 1.
[3] Migration exceedances only occurred during July/August; therefore, only possible concern if salmonids migrating upstream at this time.
[4] No continuous temperature data were available to determine whether this was a factor of decline (other determinations for Newaukum and Springbrook based on discrete data).
N/A = Not applicable; salmonids are not known to spawn in the Lower Green or Duwamish subbasins.

DATA GAPS

This section summarizes some of the data gaps that exist for the mainstem and major tributaries based on the findings of this report.

1. **Spatial availability of water quality data.** The spatial availability of water quality data is highly variable across the watershed. There is a paucity of sampling locations for the mainstem of the Green River, with only four sampling stations between the Duwamish River (RM 11) and the Tacoma diversion dam (RM 61). Conversely, some tributaries such as Newaukum and Soos creeks have a dense spatial representation, with 18 and 17 sampling stations, respectively. Such sparse coverage in some subbasins could potentially overlook some areas with impaired water quality in the Green River, and result in greater uncertainty in this assessment.

2. **Lack of continuous temperature data for some subbasins.** There is a lack of continuous temperature data for the mainstem and several tributaries. Continuous data are necessary to determine maximum daily temperatures and the duration of temperature exceedances that have the greatest potential to impact salmonids. For example, temperature conditions in Crisp Creek were determined to be unlikely as a factor of decline based on routine monthly monitoring. However, examination of continuous temperature data indicated somewhat frequent small exceedances of the proposed rearing and spawning standards leading to a possible factor of decline determination.

3. **No or insufficient data for some parameters**. Data are lacking for many of the water quality parameters that may adversely affect salmon. Available TSS data do not include any information on the duration of exposure, which is needed to evaluate accurately potential effects on salmonids. In an urban watershed with extensive commercial and industrial development characteristic of the Lower Green River and Duwamish River segments, other

parameters that could be of concern include metals, pesticides and herbicides, PAHs, and phthalate esters. There is a shortage of data available for these parameters in the water column. Most of the existing data is for sediments.

4. **Lack of baseflow data for metals**. The majority of the ambient metals data in the Green River watershed were collected as part of the stormwater monitoring program; therefore, baseflow metals concentrations are generally unknown. Furthermore, between 1996 and 1999, metals data were available in only seven locations in the watershed. Therefore, the subbasins are not well characterized for metals with the current data.

5. **No or insufficient data on additive or synergistic effects**. There is insufficient information on the combined effects of toxicants, such as metals or organic chemicals, on salmonids. Additivity is the characteristic property of a mixture of toxicants that exhibits a total toxic effect equal to the arithmetic sum of the effects of the individual toxicants (U.S. EPA 1991). Synergism is the characteristic property of a mixture of toxicants that exhibits a greater-than-additive total toxic effect (U.S. EPA 1991).

6. **Poor or insufficient data on aquatic insects**. Unlike chemical data that yield a snapshot of aquatic conditions at the time of sampling, aquatic insects provide an integrated view of overall water quality conditions at a given location. Unfortunately, the only available aquatic insect data (as measured by B-IBI) in the Green River basin was for the Soos Creek subbasin from 1995, 1997, and 1998, and from selected stations on the Green and two tributaries in 1999. Thus, this is a data gap for the basin as a whole.

7. **Historic water quality limitations for salmonids**. There is a need to define closer links between water quality data and site conditions with the historic, current, and potential future distribution of salmonids. It is likely that water quality conditions limited salmonid distribution in the past, even without extensive human activities. For instance, DO and temperature conditions in areas with extensive open water wetlands may not be compatible with fish presence. Also, the DO and temperature requirements for salmonid migration, rearing, and spawning/incubation vary considerably.

8. **Lack of reference stream site information**. There is an interest in having reference sites based on different geomorphic systems to define background water quality conditions. Without reference sites, it is difficult to define the relative contribution of anthropogenic activities to degraded water quality conditions.

1. INTRODUCTION

This report provides an assessment of the water quality conditions in the Green/Duwamish watershed focusing on water quality concerns for anadromous and resident salmonids. The specific objectives of the report are as follows:

- To identify subbasins/streams with impaired water quality and what parameters are likely causing the impairment;
- To identify subbasins/streams with good water quality and what parameters are not likely to be of concern;
- To categorize parameters as possible, probable, unlikely, or unknown water quality factors of decline for salmonids;
- To identify trends in water quality conditions, where possible;
- To summarize water quality impairment based on Washington State's 303(d) listings; and
- To identify major water quality data gaps for potential future investigations.

SCOPE

The scope of this report includes an assessment of water quality in the mainstem of the Green River and Duwamish Estuary, as well as the major tributaries to the Green River. These tributaries include the Newaukum Creek subbasin, Crisp Creek, Soos Creek subbasin, Mill/Hill Creek subbasin, and Black River (Springbrook Creek) subbasin (Figures WQ-1 through WQ-3). The scope does not include an assessment of tributaries in the upper Green River or the Duwamish Estuary, nor does it include the independent tributaries to Puget Sound or Elliott Bay.[2]

The water quality assessment is based on existing water quality reports and from analysis of water quality data collected during the past four years (1996-1999). Summaries from existing water quality reports (published within the past decade) are presented for different segments of the mainstem and its tributaries, where available. Current water quality conditions are characterized from recent water quality data from the King County Streams monitoring program and samples collected by the Muckleshoot Indian Tribe Fisheries Department (MITFD) for the Newaukum and Soos subbasins. To ensure that the summary accurately reflects existing and not historical conditions, only the last four years of data were evaluated. Therefore, all of the data included in this summary were collected between October 1996 and December 1999. These data were collected as part of routine monthly stream monitoring or targeted monitoring of streams during storm conditions. New data were not collected as a part of this evaluation.

This report focuses on water quality parameters that may cause direct toxicity or harm to salmonids. These parameters include temperature, dissolved oxygen (DO), total suspended solids

[2] King County's Central Puget Sound Team is conducting a separate evaluation of water quality in Elliott Bay and the independent tributaries to Puget Sound.

(TSS), pH, ammonia, and metals. This report does not assess to what extent temperature conditions are a concern for bull trout, because of a lack of sufficient data and information on bull trout distribution in the watershed. Data were not readily available for other parameters, such as organic chemicals (e.g., pesticides), that may also cause direct toxicity, or direct and indirect adverse impacts to salmonids. Other water quality parameters, such as increased levels of nitrate, phosphorus, and fecal coliforms can result in water quality concerns; however, they were not evaluated in this report as they are not thought to have direct effects on salmonids.

To assess whether water quality may result in conditions that are known to be or may be a factor of decline for salmonids, water quality data were compared to Washington State water quality standards (WAC 173-201A), the proposed new state water quality standards for temperature and DO, EPA water quality criteria and appropriate toxicity screening thresholds from the scientific literature.

In addition, stream segments throughout the Green/Duwamish watershed that are listed on the State's 1998 303(d) list of impaired water bodies are identified. Section 303(d) of the Clean Water Act requires the State to identify those water bodies that do not meet water quality standards. The State is then responsible for prioritizing the list and developing Total Maximum Daily Loads (TMDLs) for every water body and pollutant on the list. Some segments in the Green/Duwamish watershed are also listed for sediments and tissues, but they are beyond the scope of this report.

REPORT ORGANIZATION

Following this section, the report includes an overall discussion on the available water quality data (section 2). Section 2 presents the locations of the sampling data, more detail on the parameters evaluated and a summary of the major data gaps common throughout the report. Section 3 is a brief summary of the available biological data used in this report. Section 4 presents the existing and proposed Washington State water quality standards and EPA water quality criteria used in this report. For those parameters without standards, a summary of the toxicity thresholds used from the scientific literature is presented. Finally, Section 4 presents a summary of the 303(d) listed waterbody segments in the Green/Duwamish Watershed. Section 5 presents the detailed water quality assessment by subbasin. The subbasins include the mainstem (Upper, Middle and Lower Green River, and the Duwamish River) and five tributaries (Crisp, Newaukum, Soos, and Mill (Hill) creeks, and the Black (Springbrook) River).

2. AVAILABLE WATER QUALITY DATA

Most of the water quality data used in this report for the Green/Duwamish watershed has been collected by King County Department of Natural Resources (previously Metro), but data has also been collected by the Department of Ecology, MITFD, USGS, Corps of Engineers, Port of Seattle, Boeing, City of Tacoma, and selected cities within the basin. For the existing conditions analysis in this report only the King County, MITFD, and City of Tacoma data were used, because they were recent (1996 to 1999), readily available, and in a useable format. A variety of reports and studies containing water quality data were also available for specific sub-basins. The more recent studies are summarized in this report. Students at Green River Community College sampled water on several occasions in the 1980s, but there is little documentation of these data and no available QA/QC, so it was not used in the following analysis.

King County (Metro) has been sampling in the Green/Duwamish watershed for a variety of water quality parameters since 1970. In the mid-1970s, it was recommended that Metro institute an ongoing program to monitor water quality in the 26 subbasins within the western third of King County (Metro 1978). The goal of the monitoring program was to provide information about local surface waters in the Seattle Metropolitan area in support of programs designed to protect water quality and abate water pollution. Fourteen stations in the Green River basin have been monitored as part of this program since the mid-1970s.

The frequencies of sampling and types of indicators measured have varied over the years, but samples have been collected at least monthly. Samples for the King County Streams Monitoring Program were collected beneath the water surface, in the top meter and as close to the center of the channel as possible. For the Duwamish River Water Quality Assessment (King County 1999), King County also collected samples at depth (one meter above bottom to a maximum depth of 20 meters) and near the banks in the Duwamish River.

SAMPLING LOCATIONS AND FREQUENCY

Water quality data were available from 66 locations throughout the Green River basin as part of the King County Streams Monitoring Program, MITFD and the City of Tacoma Public Utilities Water Quality Division monitoring programs for the time period investigated (1996-1999). King County and MITFD sampling occurs routinely as part of monthly monitoring (typically during ambient flow conditions) and specifically during storm conditions. Although most data were collected during both ambient and storm conditions, the majority of the metals sampling occurred only during storm conditions. Storms are characterized by at least 0.25 inches of rain within a 24-hour period with at least 24 hours of dry antecedent conditions. City of Tacoma monitoring occurred on a weekly basis. Figures WQ-1 through WQ-3 identify all of the sampling locations analyzed in this report from the King County and Muckleshoot Indian Tribe Streams Program as well as the City of Tacoma Public Utilities Water Quality Division. All data used were from samples collected between October 1996 and December 1999. In addition, continuous temperature monitoring data were available for stations in the Soos Creek (Covington, Jenkins, Little Soos, and Soosette), Mill Creek and Crisp Creek subbasins from the King County Stream Gauging Program and USGS (Big Soos Creek).

SUMMARY OF PARAMETERS INCLUDED IN ANALYSIS

This report focuses mostly on those water quality parameters that are potential water quality factors of decline for salmonids, based on the scientific literature or where water quality standards have been promulgated. It does not contain a review of all water quality data collected in the watershed. For instance, fecal coliforms are the most common water quality parameter listed on the 1998 303(d) list in the watershed, but because fecal coliforms are thought to not adversely affect fish, they are not discussed in this report.

Parameters covered in this report include:

- Conventionals (temperature, dissolved oxygen, pH, turbidity and total suspended solids);

- Ammonia-nitrogen, and
- Metals (such as copper, cadmium, and zinc).

Other parameters that are known to adversely affect fish, but for which little or no data were available or standards not developed (e.g., pesticides, petroleum aromatic hydrocarbons (PAHs) and phthalates), are not analyzed in this report. The only exception was pentachlorophenol, where data from the Duwamish River were compared with marine standards.

DATA GAPS

The spatial availability of water quality data is highly variable across the watershed. There is a paucity of sampling locations for the main stem of the Green River for which King County data are available, with only four sampling stations between the Duwamish River (RM 11) and the Tacoma diversion dam (RM 61). There are two sampling stations in the Lower Green River spanning 21 miles, and only two stations in the Middle Green River, spanning 29 miles. Conversely, some tributaries such as Newaukum and Soos creeks have a dense spatial representation, with 18 and 17 sampling stations, respectively. Such sparse coverage in some subbasins could potentially overlook some areas with impaired water quality in the Green River, and result in greater uncertainty in this assessment.

There are probably sufficient data to characterize temperature, DO, pH, and ammonia at each of the sampling locations for purposes of assessing preliminary areas of concern for salmonids. However, as noted above, the current station locations do not yield adequate spatial coverage. Continuous temperature data exist for only some subbasins; thus, for other subbasins, it was not possible to determine maximum temperatures and the duration of temperature exceedances that have the greatest potential to impact salmonids.

Data are lacking for many of the other water quality parameters that may adversely affect salmon. In an urban watershed with extensive commercial and industrial development characteristic of the Lower Green River and Duwamish River segments (RM 0 – 32), typical parameters that can be of concern include metals, pesticides and herbicides, PAHs, TSS, and phthalate esters. Potential sources of these pollutants in stormwater and CSOs are described below:

- Metals can originate from a variety of sources including exposed metal surfaces, treated lumber and vehicles, including brake pad residues and tires.
- Pesticides and herbicides (e.g., 2,4-D, Diazinon, Malithion) applied to crops and landscaping can be transported into nearby streams via wind drift and stormwater runoff. This is an issue for agricultural areas such as those in the Middle Green River basin, as well as commercial and residential areas in the more developed portions of the basin (Hoffman et al. 2000).
- PAHs are formed as the result of incomplete combustion of organic compounds with insufficient oxygen (U.S. EPA 1980a), and have been detected in cigarette smoke and gasoline exhaust condensates (U.S. EPA 1980b).

- Phthalate esters are a large group of chemicals used primarily as plasticizers, which can be present in concentrations up to 60 percent of the total weight of a plastic. Phthalate esters are loosely linked to the plastic polymers and are easily extracted (Mathur 1974 as cited by U.S. EPA 1980c).

- In sub-basins with extensive impervious surface coverage, such as the Lower Green River, TSS is a concern due to washoff of urban surfaces as well as increased stormwater runoff which can lead to instream erosion. However, because TSS effects are highly dependent on the duration of exposure, information on both concentration *and* duration are needed to evaluate its effects to salmonids.

Concentrations of pesticides and herbicides in surface water are expected to be highest in highly developed areas (including areas with extensive homeowner usage) and where there are intensive agricultural activities (such as in the Middle Green River basin) (Hoffman et al. 2000). There is also some pesticide use in the Upper Green River basin along access roads and utility rights-of-way. There likely are fewer sources of metals, PAHs, phthalate esters and TSS in the less developed areas, however, these parameters should be evaluated to characterize the baseline and upstream conditions.

The majority of the metals data in the Green River watershed were collected as part of the stormwater monitoring program; therefore, baseflow metals concentrations are generally not available. Furthermore, between 1996 and 1999, metals data were available in only seven locations in the watershed. Therefore, the subbasins are not well characterized for metals with the current data.

3. AVAILABLE BIOLOGICAL DATA

King County uses a method called the Benthic Index of Biotic Integrity, or B-IBI, as a "report card" for measuring the health of the benthic aquatic insect community and for the stream ecosystem as a whole (Fore et al. 1997). Data are limited for the Green River basin, but the B-IBI measure still provides a useful tool to compare different subbasins with one another.

BENTHIC INDEX OF BIOTIC INTEGRITY

The B-IBI is composed of ten "metrics" (Fore et al. 1997). Metrics measure different aspects of stream biology, including the diversity of species, abundance of certain species, presence/absence of species that are tolerant and intolerant to pollution, their reproductive strategy, feeding ecology, and population structure. Each metric is assigned a value of 1, 3, or 5 depending on what species are present at a site. A score of 5 is used to indicate little or no degradation, a score of 3 to indicate moderate degradation, and a score of 1 to indicate severe degradation. All ten metric scores are added together to get a value ranging from 10 to 50. A score of 46-50 is generally considered excellent, 38-44 good, 28-36 fair, 18-26 poor and 10-16 very poor.

It is important to note that scores vary across a watershed and region based on a combination of physical conditions and water quality. The type of substrate, flow, and riparian buffer/vegetation can influence the B-IBI in addition to water quality conditions (e.g., temperature, DO, TSS, metals).

SAMPLING LOCATIONS

Aquatic insect data were collected at eight locations by staff from King County in the Soos Creek subbasin on two or three occasions in 1995, 1997 and 1998. Additionally, data were also collected by volunteers in 1999 under the direction of the SalmonWeb program (Salmon Web 2000). Seven locations on the mainstem of the Green River, one location on Mill Creek (Kent) in the Black River Basin, and one location on Meridian Valley Creek in the Big Soos Creek subbasin were sampled. SalmonWeb (2000) noted that the protocols use sampling methodologies and scoring criteria developed and calibrated for small streams (2^{nd} to 4^{th} order), and for this reason the results for the Green River should be considered preliminary. Results of the biological monitoring are presented in the subbasin sections below.

4. IDENTIFICATION OF WATER QUALITY STANDARDS

Throughout this chapter, references are made to various water quality standards for comparison purposes. These include: (1) Water Quality Standards for Surface Waters of the State of Washington, Chapter 173-201A WAC, (2) National Recommended Water Quality Criteria for Priority Toxic Pollutants (63 FR 68354-68364), and (3) 1999 Update of Ambient Water Quality Criteria for Ammonia (U.S. EPA 1999). In addition, comparisons are also made with Ecology's proposed use-based standards for temperature (Hicks 2000a) and DO (Hicks 2000b) that take into account requirements of salmonids for rearing, spawning and incubation. These new standards are scheduled for public hearing in March 2001 and scheduled for adoption by August 2001. Thus, they are still undergoing stakeholder review and agency consideration. For indicators where no water quality standards exist, some comparisons are made with other streams or toxicity values from the scientific literature.

STATE WATER QUALITY DESIGNATIONS AND BENEFICIAL USES

The Water Quality Standards for Surface Waters of the State of Washington (Chapter 173-201A WAC) provides a set of classifications for water bodies in the state, ranging from Class AA (extraordinary) to Class C (fair) based on the "beneficial uses" of the water, or what uses the water might support. The beneficial uses describe allowable water uses (domestic, industrial, agricultural), salmon fishery uses (migration, rearing, spawning, harvesting) and contact recreation (swimming, wading) for each classification. Table WQ-1 summarizes the state water quality beneficial uses for each classification.

Table WQ-1. Water quality beneficial uses for surface waters of the State of Washington.			
Characteristic/WQ Parameter	Class AA (Extraordinary) (Upper Green R.)	Class A (Excellent) (Lower Green R.)	Class B (Good) (Duwamish R.)
Allowable Water Uses	Domestic Industrial Agricultural	Domestic Industrial Agricultural	Industrial Agricultural
Salmonid Uses	Migration Rearing Spawning Harvesting	Migration Rearing Spawning Harvesting	Migration Rearing Harvesting
Contact Recreation	Primary(swimming)	Primary(swimming)	Secondary (wading)

The Duwamish River, from its mouth at Elliott Bay to the confluence with the Black River (river mile 11.0) is designated Class B. The lower and middle Green River is designated Class A from river mile 11.0 to river mile 42.3 at Flaming Geyser State Park. From river mile 42.3 to the headwaters, the Green River is designated Class AA. The Black River, Mill Creek, Soos Creek, Crisp Creek, and Newaukum Creek subbasins are all designated Class A. All tributaries to the Green River above river mile 42.3 are designated Class AA (see Figures WQ-1 through WQ-3 for river mile markings).

STANDARDS FOR WATER QUALITY PARAMETERS

In this section, the various standards/criteria and toxicity thresholds from the scientific literature used in this assessment are presented. Wherever possible, the water quality data were compared to state and federal standards to estimate which parameters at specific locations may potentially be of concern for salmonids. The National Marine Fisheries Service and U.S. Fish and Wildlife Service have raised the issue of whether water quality standards are adequate to protect listed salmonids. Ecology is proposing new use-based state standards (with salmon-specific thresholds) to address these concerns. [It is important to note that these standards (based on rearing, spawning and incubation needs for salmonids) have not yet been adopted.] A description of the standards and thresholds used in this report to characterize the existing conditions is provided below.

The state water quality standards contain numerical and narrative standards. Numerical standards consist of minimum levels or concentrations of specific water quality parameters that are established to protect aquatic biota and support beneficial uses. Different levels or concentrations have been established for temperature, turbidity, pH, DO, and fecal coliform bacteria based on the beneficial uses for various water quality class designations. For other parameters, such as metals and organic chemicals, the concentrations do not change based on the designated classification. Table WQ-2 summarizes the numeric state water quality standards for temperature, turbidity, pH, DO and fecal coliforms in freshwater for each of the three classifications present in the Green/Duwamish watershed.

Table WQ-2. Water quality standards for freshwater based on beneficial use classification.			
Characteristic/ WQ Parameter	**Class AA (Extraordinary) (Upper Green Ri.)**	**Class A (Excellent) (Lower Green Ri.)**	**Class B (Good) (Duwamish Ri.)**
Temperature (^oC)	< 16	< 18	< 21
pH	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5
Dissolved Oxygen (mg/L)	> 9.5	> 8.0	> 6.5
Turbidity (NTU)	< 5 over background when <50 NTU, <10% increase when over 50 NTU	< 5 over background when <50 NTU, <10% increase when over 50 NTU	< 10 over background when <50 NTU, <20% increase when over 50 NTU
Fecal Coliforms (Colonies/100mL)	GM < 50, not more than 10% over 100	GM < 100, not more than 10% over 200	GM < 200, not more than 10% over 400

Narrative standards are designed to protect beneficial uses in the absence of numeric criteria. Narrative standards can be used to establish levels of protection for parameters where numeric standards do not exist and to enforce the states antidegradation policy (Chapter 173-201A-070 WAC).

More detailed discussions of these standards are presented below. Also included in these detailed discussions are the proposed use-based standards for temperature and DO, the metals standards, and the toxicity thresholds from the scientific literature for those parameters lacking state or federal standards.

TEMPERATURE

Existing state temperature standards are based on the surface water classification (see Table WQ-2). In addition to these, there are marine water standards that were used for the Duwamish Estuary. For marine water, Class B surface waters (Duwamish River) shall not exceed 19°C; there are no Class A or Class AA marine surface waters in the Green/Duwamish watershed. Analysis in support of Ecology's proposed use-based[3] standards has determined that the existing standards are inadequate to fully protect all aquatic communities (Hicks 2000a). Therefore, several new alternative temperature standards have been proposed. Ecology's preferred alternative is as follows:

- Waters used for *spawning* by Pacific salmon, steelhead trout, or cutthroat trout: Human-caused conditions and activities are not to cause temperatures to exceed 15 °C as a moving 7-day average of the daily maximum temperatures, with no single daily maximum temperature greater than 17.5 °C from June 1-September 14; and 12 °C as a 7-day average of the daily maximum temperatures; with no single daily maximum temperature exceeding 14.5 °C during the period from September 15-May 31.

[3] Applying use-based standards requires that waterbodies be assigned to appropriate use-categories, such as char spawning or salmon spawning, etc. Not all use-category definitions are detailed here (e.g., char spawning, warm water species spawning) as they are either not applicable to the Green-Duwamish watershed or superceded by a more stringent use-category standard.

- Waters used for *rearing, migration, or holding by adult or juvenile* Pacific salmon, steelhead trout, or cutthroat trout: Human-caused conditions and activities are not to cause temperatures to exceed 15 °C as a moving 7-day average of the daily maximum temperatures, with no single daily maximum temperature greater than 17.5 °C.

In the Green/Duwamish Watershed, salmonid spawning starts at RM 24 in the Lower Green River and continues upstream. Salmonid spawning does not occur in the Duwamish River because of several factors, including the influence of the saltwater wedge that extends up to the turning basin (RM 11). Therefore, in this analysis the spawning temperature standard was applied to all subbasins except for the Duwamish River. The rearing standard was applied to all subbasins including the Duwamish River.

Seven-day average temperature data were not available for many of the stations being evaluated. For such stations, discrete data were compared with the 17.5°C and 14.5°C single daily maximum proposed standards for rearing and spawning waters, respectively. Daily maximum temperatures rising above 21°C are widely cited as causing a barrier to migrating adult chinook salmon (Hicks 2000a). When applicable, this migration threshold was included in the analysis. Where continuous temperature data were available, data were compared with the 15°C and 12°C 7-day average daily maximum for rearing and spawning waters, respectively. This report does not assess to what extent temperature conditions are a concern for bull trout, because of a lack of sufficient data and information on bull trout distribution in the Green/Duwamish Watershed.

DISSOLVED OXYGEN

As with temperature, current state DO standards are based on the surface water classification (see Table WQ-2). There are also marine water quality standards for DO that were used for the Duwamish Estuary. For marine water, Class B surface waters (Duwamish River) shall exceed 5 mg/L DO. Again, however, Ecology has re-evaluated the existing DO standards (Hicks 2000b) and proposed new use-based standards. Ecology's preferred alternative is as follows:

- During the *incubation period* for salmonids (in areas used for spawning), human-caused conditions and activities are not to cause daily minimum DO levels in the water column to fall below 10.5 mg/L. [The period from September 15 to May 31 should be used to apply the incubation criteria where more accurate waterbody-specific information is unavailable. Where such knowledge exists, the site-corrected incubation period should be formally noted in the water quality standards for the waterbody.]

- During all other times of the year or for waters used by salmonids *for life-stages other than incubation*, human-caused conditions and activities are not to cause daily minimum DO levels in the water column to fall below 8.0 mg/L.

Chinook eggs will incubate for the period from October into February depending upon spawning date and water temperature (Williams et al. 1975). However, in order to account for other salmonids spawning in the Green/Duwamish Watershed, this analysis adopted the Ecology defined incubation period of September 15th through May 31st (Hicks 2000b) for purposes of comparing water quality data to DO standards. However, some salmonids (e.g., winter and summer steelhead) may have incubation periods that overlap the June 1 through September 14th window.

In this analysis the incubation temperature standard was applied to all subbasins except for the Duwamish River from September 15th through May 31st. The rearing standard was applied year-round to all subbasins except the Duwamish River.

TURBIDITY / TOTAL SUSPENDED SOLIDS

Standards are established for turbidity based on surface water classification (see Table WQ-2). Application of this standard for discharges requires concurrent measurement of upstream (i.e., background) turbidity, and either discharge turbidity or turbidity in the downstream receiving water (Austin personal communication 2000). No concurrent data for upstream and downstream locations were available for point sources; therefore, the potential impacts of turbidity could not be quantified for this analysis.

As an alternative, we used total suspended solids (TSS) data to evaluate adverse effects to salmonids from suspended sediments in the water column. In addition, most of the studies conducted on the effects of suspended sediments measure TSS rather than turbidity. Because Ecology does not have water quality standards for TSS, data were used from the scientific literature to establish thresholds for salmonids.

Suspended sediment generally includes particles less than 0.25 mm (Newcombe and Jensen 1996), and is usually measured in mg/L. Various recommendations of what levels are adequate for fish protection have been proposed (NAS 1973, U.S. EPA 1976, EIFAC 1964, Alabaster and Lloyd 1982, U.S. EPA 1986, Lloyd 1987). Among these documents the most frequently-cited level of suspended sediment below which adverse effects to fish are unlikely to occur was 25 mg/L (Lloyd 1987).

Recent reviews of the available literature have determined that the duration of the exposure for salmon is equally as important as concentration relative to toxicity (Newcombe and Jensen 1996). Therefore, one cannot evaluate the effects of a specific suspended sediment concentration without considering its duration. For example, extremely high pulses (>1000 mg/L) can be sustained for several days, but sub-lethal and adverse behavioral effects can be important for streams that exhibit chronic (long-term) suspended sediment loading even at relatively low concentrations (around 20 mg/L). Sub-lethal effects could be expected from exposure to 31 mg/L for a period greater than three to seven hours, or from a 215 mg/L exposure over a period greater than one hour (Newcombe and Jensen 1996).

Another adverse effect of increased suspended sediments on salmonids is an increase in the concentration of fine sediments in the streambed substrate. Fine sediments adversely affect survival during egg incubation by coating egg surfaces or by clogging interstitial gravel spaces and reducing water flow (i.e., reduction in dissolved oxygen) or trapping emerging fry (Chapman 1988). In addition to direct mortality, fine sediments can result in delayed emergence or smaller fry (Chapman 1988). Furthermore, fine sediment can affect fry survival by filling the interstitial areas between cobbles and other small-sized substrate and thereby reducing important hiding places for rearing fish. Fine sediment is also know to negatively affect macroinvertebrate communities (May et al. 1997), because of the reduction of available surface area and interstitial areas used as cover (Cordone and Kelly 1961). Therefore, fine sediment also indirectly impacts rearing salmonids by reducing important prey items. The water quality data evaluated for this study do not have information on fine sediments in the streambed substrate, so this will not be evaluated in this report.

pH

The current state pH standards for freshwater are 6.5 to 8.5 for all classifications (see Table WQ-2). As with temperature and DO, there are also marine water standards that were used for the Duwamish Estuary. For marine water, the pH standards are 7.0 to 8.5 for all classifications. Direct effects to salmonids are not expected in this range, however the toxicity of some chemicals (e.g., metals and ammonia) is greatly influenced by pH. Data were evaluated against the state standard. Data were also used to help evaluate the ammonia and pentachlorophenol toxicity standards and thresholds (see below).

AMMONIA-NITROGEN

In aqueous solution, ammonia primarily exists in two forms, unionized ammonia (NH_3) and ammonium ion (NH_4^+). The state standards are based on the unionized fraction of ammonia because it is much more toxic than ammonium ion (U.S. EPA 1986). Unionized ammonia is the more toxic form because it is a neutral molecule and thus able to diffuse across epithelial membranes of aquatic organisms (e.g., fish gills) much more readily than the charged ion (U.S. EPA 1998). The unionized fraction is both pH and temperature dependent; therefore the standard is pH and temperature dependent. As pH and temperature increase, ammonia toxicity increases, and the standards decrease. In addition, the standards change (i.e., become less stringent) if the surface water is not used by salmonids. The standards used for this analysis are based on salmonids being present.

In 1998, EPA revised the freshwater national ammonia water quality criteria to account for total ammonia (both NH_3 + NH_4^+). However, in developing the new chronic criteria, EPA excluded the salmonid (i.e., rainbow trout) toxicity data because of variability in the study results. This resulted in a less stringent freshwater chronic standard. Because of the uncertainty regarding the level of protection of the new EPA chronic ammonia criteria for salmonids, Ecology is considering adopting EPA's new acute criterion[4], while maintaining their existing chronic criterion (C. Neimi personal communication 2000). Therefore, both the existing state standards and the new EPA criteria were used in this analysis.

Available pH and temperature data for the Green River watershed were averaged for each sample location to develop acute and chronic ammonia freshwater standards specific to each location. Depending on the receiving water's pH and temperature, EPA standards in freshwater ranged from 2.86 to 38.99 mg/L (acute) and 1.40 to 7.09 mg/L (chronic). When converted to total ammonia, state freshwater standards ranged from 2.38 to 35.80 mg/L (acute) and 0.75 to 2.70 mg/L (chronic). For the Duwamish River, conservative state and EPA marine standards were used representing the worst-case combination of pH, temperature and salinity based on the 1996

---

[4] The 1999 EPA acute criterion continues to incorporate salmonid toxicity data; only the 1999 chronic criterion excluded it.

to 1999 data. When converted to total ammonia, the acute marine standard was 1.3 mg/L and the chronic marine standard was 0.2 mg/L.

METALS AND PENTACHLOROPHENOL

In fish, at exposure concentrations that produce acute effects, gills are the principal site of toxicity (Evans 1987, Wood 1992). Gill function includes gas exchange and active ion uptake to counter ion changes down their electrochemical gradients. Metals bind to anionic sites on the gills and disrupt gill transport functions. If a metal cannot bind to the site of uptake, it will not be acutely toxic (Bergman and Dorward-King 1997).

Measurement of the total recoverable metal (TRM) includes some fraction of the metal that is bound to suspended solids or is strongly complexed with organic matter or other ligands and cannot bind to gill receptor sites. Therefore, standards for the majority of the metals are based on the dissolved fraction of the metal, as opposed to the TRM, as it more closely approximates the metal's bioavailable fraction, and thus, its toxicity (Prothro 1993, U.S. EPA 1993). On the other hand, metals bound to suspended solids may settle and contribute to sediment metal loads. These sediments may be incidentally ingested by salmonids or accumulate into benthic organisms and thus enter into the food chain. However, mechanisms of chronic toxicity from dietary exposure are not understood and therefore beyond the scope of this analysis.

The National Recommended Water Quality Criteria for Priority Toxic Pollutants were developed by EPA and subsequently adopted by Ecology for Washington State. Both acute (short-term) and chronic (long-term) criteria have been established for various metals and organic chemicals in fresh and marine waters. The acute standards are based on short-term toxicity tests evaluating lethal endpoints and reflect the highest surface water concentration to which aquatic life can be exposed for a brief period of time without causing unacceptable mortality levels. The chronic standards are based on long-term sub-lethal toxicity tests with endpoints such as survival, growth, reproduction and development, and reflect the highest instream concentration of a toxicant to which aquatic life can be exposed indefinitely without causing an unacceptable effect (U.S. EPA 1991).

The state water quality standards for metals and pentachlorophenol are listed in Table WQ-3. As noted in the table, a number of the freshwater standards are dependent on the hardness of the receiving water. The water hardness affects the bioavailable[5] fraction of the metal. As the hardness increases, the metal is less bioavailable, and therefore, less toxic. For those metals that are hardness dependent, a hardness of 40.5 mg/L $CaCO_3$ was used for the Middle and Upper Green River and their tributaries. This value was calculated from the average of all the available calcium and magnesium concentration data (1996 through 1999) within the Green River watershed.

[5] Bioavailability is the degree to which a contaminant in a potential source is free for uptake (movement into or onto an organism) (Hamelink et al. 1994).

Table WQ-3. State water quality standards for metals and pentachlorophenol (µg/L).				
	Freshwater		Marine	
Parameter	Acute	Chronic	Acute	Chronic
Aluminum, total	750**	87**	N/A	N/A
Arsenic, dissolved	360	190	69	36
Cadmium, dissolved*	1.4	0.5	42	9.3
Chromium (VI), dissolved	15	10	1100	50
Chromium (III), total*	261.6	84.8	N/A	N/A
Copper, dissolved*	7.3	5.2	4.8	3.1
Lead, dissolved*	23.8	0.9	210	81
Mercury, dissolved	2.1	N/A	1.8	N/A
Mercury, total	N/A	0.012	N/A	0.025
Nickel, dissolved*	658.4	73.1	74	8.2
Pentachlorophenol	***	***	13	7.9
Selenium, total	20	5	290	71
Silver, dissolved*	0.7	N/A	1.9	N/A
Zinc, dissolved*	66.3	60.6	90	8.1

* Criteria hardness dependent. Value shown based on 40.5 mg/L $CaCO_3$.
** Chapter 173-201A does not contain numeric water quality criteria for aluminum, so the EPA water quality criteria for aluminum is used.
*** Freshwater pentachlorophenol standards were not included as no freshwater pentachlorophenol data were available.
N/A = not available.

Water quality data for metals and pentachlorophenol were compared to the standards shown in Table WQ-3 to determine potential factors of decline for salmonids. The freshwater standards were applied throughout the watershed, except for the Duwamish. In the Duwamish, at least 90 percent of the samples would be classified as marine according to WAC 173-201A-060 (salinity of greater than or equal to one part per thousand). The small percentage of samples below one part per thousand were measured either on the surface at the upper end of the Duwamish River or during high river flows combined with low tides. However, it is unlikely that true freshwater species will inhabit an estuarine environment where salinity exceeds one part per thousand over 90 percent of the time. Therefore, marine standards were applied in the Duwamish.

Because acute standards represent a one-hour average concentration not to be exceeded, the maximum values for each of the parameters were compared to the acute water quality standards. On the other hand, chronic standards represent the four-day average concentration not to be exceeded. Therefore, arithmetic mean values (or geometric mean values when the coefficient of variation was greater than 100 percent) were compared to the chronic water quality standards.

It is important to note that detection limits for some metals were higher than their corresponding standards or criteria. For example, method detection limits for the selenium (50 µg/L) analyses conducted prior to 1998 were greater than the state acute and chronic water quality standards for freshwater (20 and 5 µg/L, respectively). In addition, method detection limits for aluminum (100 µg/L) were greater than the EPA chronic freshwater criterion (87 µg/L). Where these metals were not detected, comparisons to the appropriate standards or criteria could not be made, as the true concentration was unknown. When detected, though, concentrations of these metals were known to be higher than the appropriate standards or criteria, and the detection limits were not an issue.

Similarly, method detection limits for total mercury (0.2 µg/L) were greater than the state chronic freshwater standard (0.012 µg/L). However, this standard is based on the protection of human health from consuming fish and is lower than the levels associated with toxicity to aquatic life, including salmonids (0.77 µg/L, 63 FR 68354-68364). Therefore, because mercury was never detected in freshwater and the method detection limits are below levels associated with toxicity to aquatic life, mercury in the water column is not expected to be of concern to aquatic life, including salmonids.

DESIGNATION OF 303(D) LISTED WATER BODIES

Numerous stream systems throughout the Green/Duwamish watershed are listed on the State's 1998 303(d) list of impaired water bodies. Section 303(d) of the Clean Water Act (CWA) requires the State to identify those water bodies that do not meet water quality standards. The State is then responsible for prioritizing the list and developing Total Maximum Daily Loads (TMDLs) for every water body and pollutant on the list. In the Green/Duwamish watershed, water body segments have been listed for failing to meet water quality standards for one or more of the following parameters: fecal coliform, temperature, DO, pH, ammonia, and water column metals (cadmium, chromium, copper, mercury, zinc). The water bodies and parameters on the 1998 303(d) list are shown in Table WQ-4 and Figure WQ-4.

It is important to note that there has been no comprehensive assessment of water quality to determine which water body segments do or do not meet water quality standards. The water bodies on the 1998 303(d) list mostly reflect exceedances where water quality data have been collected. It should not be inferred that all other segments meet water quality standards. Some segments have been regularly monitored and meet water quality standards; however, other segments may exceed standards, but are not on the 303(d) list because they have never been monitored. It is also important to note that Duwamish River sediments and tissues are also listed on the 303(d) list for numerous metals and organic chemicals. This may be a significant issue for salmonids; however, sediment quality is not the subject of this report.

Table WQ-4. Summary of Water Bodies and Parameters on 1998 303(d) List for Water.

Subbasin[1]	Specific Water Body	Parameters
Duwamish Waterway and River		pH, DO, Fecal coliform,
Lower Green River		Temperature, Fecal coliform, Chromium, Mercury
Middle Green River		Temperature, Fecal coliform
Upper Green River		Temperature
Black River	Springbrook Creek	Temperature, DO, Fecal coliform, Cadmium, Chromium, Copper, Mercury, Zinc
Hill (Mill) Creek	Hill (Mill Creek)	Temperature, DO, Fecal coliform
	Mullen Slough	Temperature, DO, Fecal coliform
Soos Creek		Temperature, DO, Fecal coliform
Newaukum Creek		DO, Fecal coliform, Ammonia-N
Crisp Creek		Fecal coliform

[1] Only particular water bodies of these subbasins are on the 303 (d) list, based on the specific location of available water quality data.

5. WATER QUALITY ASSESSMENT BY SUBBASIN

The following section provides a summary of existing water quality conditions by subbasin for four reaches along the mainstem and five tributaries. Each subsection has a brief description of the physical information about the subbasin including location, watershed area, and land use, followed by a summary of existing water quality reports for that subbasin, if available. While some of the water quality information presented from existing reports is as much as 12 years old, the information often represents good spatial coverage for the subbasin in comparison with recent data. Next, data from the King County Streams program (1996-99) is presented and comparisons are made to water quality standards and toxicity screening thresholds. This is followed by a description of any available biological data. Finally, any subbasin-specific data gaps are also identified if appropriate.

UPPER GREEN RIVER

For purposes of the Water Quality Assessment of the Green River, the watershed boundary for the upper watershed was defined as Tacoma Headworks Dam. The Upper Green River watershed drains approximately 231 square miles of mountainous and heavily timbered terrain above the City of Tacoma's Headworks and Diversion Dam (RM 61). Land use in the basin is primarily forest and used for commercial timber production and domestic water supply. There is limited recreational use, primarily in the upper more remote sections of the watershed. Approximately 42 miles of gravel forest roads and up to 824 miles of road access exist within the basin to support logging activities.

Erosion and its resulting impact on turbidity and suspended solids transport is an ongoing concern in the watershed (King County 1989). Primary causes of erosion in the watershed include logging activities, road construction and maintenance, landslides and breakdown of stream channels during peak runoff periods (King County 1989). Application of herbicides for vegetation control is carried out by several landowners along access roads and power line rights-of-way in the basin, and in some instances for broad-leaf plant control after logging. The reach of the Green River between the Tacoma diversion dam and the Howard Hanson dam (HHD) is listed on the 1998 303(d) list for temperature.

Inflow temperatures to the HHD reservoir exceed 16^{o}C during the summer in most years (USACE 1995). As a result of drawing water from the lower, colder stratum, releases from HHD during the early summer are usually below expected normal temperatures. Later in the summer and in early fall, as cooler water is depleted and warmer surface water is released, temperatures are higher than would be expected under a natural, unimpounded flow. These artificially higher temperatures can adversely affect salmon spawning behavior and may accelerate maturation of developing salmon eggs (Tacoma Public Utilities 1999).

There have been no recorded observations in the upper Green River or in the HHD reservoir where DO levels have fallen below 9.5 mg/L (the standard for Class AA waters), although there has been little sampling in these waters (TPU 1999). Turbidity is greatest during flood events and when HHD reservoir levels are low, both of which can cause water at the diversion dam to be too turbid for use by Tacoma Water. Natural flows have been artificially manipulated by the dams, resulting in modified hydrologic conditions downstream.

WATER QUALITY—EXISTING CONDITIONS

King County does not collect any water quality data in the Upper Green River as part of its stream monitoring program. However, the Tacoma Public Utilities Water Division monitors temperature and turbidity on a weekly basis at four locations (2, 4, 5 and 8) on the mainstem of the Upper Green River (Figure WQ-3). They also collect fecal coliform data, but the results are not presented in this report. The following is an analysis of the last four years of data provided by the Water Division.

Temperature

None of the 659 water temperature measurements analyzed were measured above the salmonid migration threshold (21°C), and only 10 of these exceeded the proposed salmonid rearing threshold (17.5°C). The maximum recorded water temperature was 20°C. Sixty-three of the 659 water temperature measurements exceeded the proposed salmonid spawning threshold (14.5°C), however, all of these excursions occurred between July and September. Only six of these occurred within the defined spawning season (September 15 through May 31). Taken together, these data would suggest that water temperature is not likely to be of concern for salmonids, however, water temperature readings were only taken weekly and do not necessarily represent peak temperatures.

Turbidity

The average turbidity of all 655 measurements analyzed from the four stations was 2.67 NTU, with a maximum of 234 NTU. This peak measurement probably occurred during or shortly after a storm event or some other disturbance that caused a short-term increase in turbidity. The second highest turbidity value was 22.2 NTU. All other measurements were below 20 NTU, and only 18 of 655 measurements were greater than 10 NTU. Although TSS concentration and duration data were not available, these consistently low turbidity data suggest that elevated solids are not likely to be of concern for salmonids.

BIOLOGICAL MONITORING IN THE UPPER GREEN RIVER

Aquatic insect sampling occurred at two stations on the mainstem in the upper Green River during 1999 (SalmonWeb 2000). One station was located above the Howard Hanson Dam and the other was located above the Tacoma diversion dam (RM 63.5). The B-IBI scores were 32 and 28 above the Howard Hanson and Tacoma diversion dams, respectively. These scores are characterized as fair on the B-IBI index.

DATA GAPS

Temperature, turbidity and fecal coliform data are the only water quality data available in the upper Green River. Fecal coliform data were not analyzed for this report, because fecal coliforms are not thought to be a factor of decline for salmonids. The lack of continuous temperature data is a data gap because data do not necessarily reflect maximum temperatures that have the greatest potential to impact salmonids. There is limited DO data. Thus, the lack of DO, pH, metals and organics data is a data gap.

MIDDLE GREEN RIVER

The Middle Green River basin begins at the Tacoma Diversion dam (RM 61) and continues downstream to the Auburn Narrows (RM 34) (see Figure WQ-2). Development in the basin is scattered with the largest portion of the basin in undeveloped open space. A substantial portion of the western half of the basin is used for agriculture. Most of the residential development is rural in nature, as most of the basin is on the east side of the Urban Growth Boundary. Small portions of Auburn and Black Diamond are the only urban areas in the basin, but together they constitute less than five percent of the watershed area.

The lower reach of the middle Green River sub-basin between RM 32 and RM 42.3 (west boundary of Flaming Geyser State Park) is classified as a Class A surface water in Chapter 173-201A WAC. Between RM 42.3 and the headwaters (including the Green River Gorge), the Green River and tributaries are Class AA. Temperature is the only parameter listed for the Middle Green River on the State's 303(d) list of impaired water bodies for failing to meet state surface water standards. This listing is based on multiple excursions above the state standard between RM 35 and RM 61.8 from 1991 to 1996.

Temperature data were collected by the Muckleshoot Tribe (Caldwell 1994) on the mainstem of the Green River in the summer and early fall of 1992. This was partly in response to a Corps of Engineers report (Grette and Salo 1986) that indicated that elevated Green River temperatures caused a delayed upstream migration of early-run fall chinook and may also influence utilization of the lower Green River by juvenile steelhead, chinook, and coho. The objective of the study was to document temperatures in the Green River between RM 12 and 64.5, describe the extent and duration of high summer temperatures, and investigate temperatures in deep pools and shallow stream margins. The following conclusions were drawn from this study:

- The maximum summer temperatures in 1992 were 23.5°C and 22.5°C at RM 35 (Nealy Bridge) and 41.5 (Whitney Bridge), respectively during mid August;

- Temperatures over 18°C were measured between two and three times more often at RM 13 (in the lower Green River) than RM 41.5 (Middle Green River); and

- Temperatures in deep pools between RM 35 and 41.5 were found to be the same as in other habitats. Shallow stream margins in the same reach had the potential to be 0.5-2.0°C higher than deeper habitats, depending on whether the shallow water was flowing or standing. In the shallow waters, water velocities and not water depth was the most important factor influencing temperatures.

There were no other historic reports on water quality in the middle Green with the exception of the annual Metro water quality reports from the 1980s. The King County streams program has collected water quality data since 1976 at two stations on the middle Green River.

WATER QUALITY—EXISTING CONDITIONS

The two sampling locations for which data are available between 1996 and 1999 are located above the confluence of Big Soos Creek (Station A319 at approximately RM 34.5) and above the confluence of Newaukum Creek (Station B319 at approximately RM 41.5) (see Figure WQ-2).

These locations are dominated by black cottonwood trees, and represent a more natural riparian habitat than the sampling locations of the lower Green River.

The parameters, number of samples analyzed, and number of storm samples varied for the two stations between 1996 and 1999. At station A319, temperature, DO, pH, turbidity, TSS and ammonia were analyzed for 36 to 39 samples during nonstorm conditions. These same parameters were analyzed for one storm on December 29, 1998 at station A319. For station B319, these same parameters were measured during both nonstorm (36 to 40 samples) and storm (13 to 15 samples) conditions. Additionally, total and dissolved metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) were analyzed at station B319 during storm conditions on roughly 14 and 8 occasions, respectively. Total aluminum was analyzed on three occasions during storm conditions. Comparisons of data to standards or criteria are detailed below.

Temperature

Based on water quality data from 1996 through 1999, temperatures for each location were within the Class A and proposed rearing standard ranges. A number of temperature measurements at each location exceeded the proposed spawning standard; however, most of these exceedances do not occur during the defined spawning season (September 15 through May 31). Two exceedances of the proposed spawning standard (15 and 15.1°C at A319 and B319, respectively) occurred on September 15, 1998. This would suggest that temperature may not be of concern for salmonids, however temperature readings are only taken monthly and do not necessarily represent peak temperatures during the spawning season. In addition, temperature may be of concern for other salmonids whose spawning season overlaps the June 1 through September 14 window (e.g., winter and summer steelhead).

Dissolved Oxygen

Based on water quality data from 1996 through 1999, DO concentrations for each location are always greater than the minimum Class A and proposed salmonid rearing standard (8.0 mg/L). However, 12 of 37 DO measurements at station A319 were below the proposed salmonid incubation standard (10.5 mg/L), with a minimum value of 9.4 mg/L. At station B319, 9 of 50 DO measurements were below the proposed salmonid incubation standard, with a minimum value of 8.5 mg/L. As with temperature, most of these exceedances occur in the summer and do not coincide with the defined incubation period. This would suggest that dissolved oxygen is not a factor of decline in this reach; however, DO may be of concern for any salmonids whose incubation period overlaps the June 1st through September 14th window (e.g., winter and summer steelhead).

Turbidity/TSS

Average non-storm turbidity is approximately 2 to 3 NTUs, with a peak measured storm turbidity of 84 NTUs on December 28, 1998 for the period between 1996 and 1999. Total suspended solids concentrations averaged 3 to 5 mg/L for both locations during non-storm sampling, with a peak storm measurement of 114 mg/L. Therefore, a few measurements exceed levels that could cause sub-lethal effects if the concentrations were maintained for a long enough duration. However, the duration of these elevated TSS concentrations is unknown and therefore, the potential effects cannot be determined. On average, TSS does not appear to be of concern for salmonids, although more data, including concentration and duration, are needed.

pH

The average pH of the King County data from 1996 to 1999 was 7.0. However, one of 95 measurements was 6.4, or 0.1 units below the Class A/AA minimum standard of 6.5. All other measurements were between 6.5 and 8.2. Given that only one measurement exceeded the state standard, pH is not expected to elicit any direct effects to aquatic life. Therefore pH in the middle Green River is unlikely to be of concern, although it may influence the potential toxicity of other chemicals (e.g., metals).

Ammonia

The ammonia data collected from 1996 to 1999 were below both the acute and chronic state water quality standards for ammonia. Therefore, ammonia is not expected to be of concern for salmonids.

Metals

The metals evaluated here (aluminum, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) suggest that they are not of concern, with the possible exception of aluminum. Although there are no state water quality standards for aluminum, all three aluminum samples exceeded the EPA chronic water quality criterion (87 µg/L). One of the three samples (1,960 µg/L) exceeded the EPA *acute* water quality criterion (750 µg/L). Although the limited data exceed the EPA criterion, it is not likely in a toxic form because the analytical method for determining total recoverable aluminum probably dissolves some aluminum that is not toxic and cannot be converted to a toxic form under natural conditions (U.S. EPA 1988). In addition, these data were collected under storm conditions where elevated suspended solids and organic matter concentrations tends to bind more of the dissolved metal, thereby reducing its bioavailability[6]. However, because data are limited, further evaluations of aluminum should be conducted to confirm whether it is of concern for salmonids.

The same pattern for the basin as a whole is applicable to the Middle Green River data with regards to the detection limits for mercury and selenium (see section 4).

BIOLOGICAL MONITORING IN THE MIDDLE GREEN RIVER

Aquatic insect sampling occurred at four stations on the mainstem of the middle Green River during 1999 (SalmonWeb 2000). Table WQ-5 shows the B-IBI scores for the four locations in the middle Green River from the SalmonWeb data. There was a very small range in scores (28-30), with all scores characterized as fair on the B-IBI index.

[6] Bioavailability is the degree to which a contaminant in a potential source is free for uptake (movement into or onto an organism) (Hamelink et al. 1994).

Table WQ-5. B-IBI scores for Middle Green River stations in 1999 (SalmonWeb 2000).	
Macroinvertebrate Monitoring Sites	**1999 Scores**
Middle Green River (below Tacoma diversion dam, RM 60.5)	30
Middle Green River (at Flaming Geyser State Park, RM 42.5)	28
Middle Green River (at Whitney Bridge, RM 41.5)	30
Middle Green River (upstream of Soos Creek confluence, RM 34)	28

DATA GAPS

There are probably sufficient data to characterize temperature, DO, pH and ammonia at Stations A319 and B319; however, no other King County data between 1996 and 1999 were available for the mainstem of the middle Green River. Therefore, the spatial variability of these parameters in the middle Green River is a data gap, especially given the length of the river in this sub-basin (approximately 30 miles). The lack of continuous temperature data is a data gap because data do not necessarily reflect daily maximum temperatures and the duration of temperature exceedances. In addition, available TSS data do not include duration, therefore, potential effects cannot be accurately evaluated. Furthermore, there are relatively few metals data (three to 15 samples), and all were collected under storm conditions. Therefore, additional metals data are needed, especially under baseline (non-storm) conditions.

Other classes of parameters for which no data were available represent significant data gaps. No data were available for pesticides and herbicides, PAHs, or phthalate esters.

LOWER GREEN RIVER

The Lower Green River basin begins at the Auburn Narrows (RM 31) and continues to just downstream of the confluence with the Black River in Tukwila (RM 11) (see Figure WQ-1). The lower Green basin is composed of two areas that are split by the Black River basin to the north and the Mill Creek basin to the south. It is mostly on the urban side of the Urban Growth Boundary and contains portions of the cities of Kent, Auburn, Tukwila, Federal Way, and SeaTac. Land uses include residential, commercial, industrial, and agricultural, as well as some major highways, including Interstate 5. There are extensive areas of office/commercial and multi-family residential development. This area has developed rapidly over the past 20 years.

The Lower Green River is classified as a Class A surface water in Chapter 173-201A WAC. Temperature, fecal coliforms[7], chromium, and mercury are listed for the Lower Green River on the State's 303(d) list of impaired water bodies for failing to meet state surface water standards. For temperature, this listing is based on multiple excursions above the state standard between RM 12.5 and RM 27 from 1991 to 1996. For mercury, this listing is based on multiple excursions measured in 1988 at Stations 0311 and 3106, as well as multiple excursions measured between Tukwila and RM 18.3 between 1987 and 1991.

There were three temperature stations in the Lower Green River included in the Muckleshoot Indian Tribe's study (Caldwell 1994) in 1992. The stations were located along the mainstem in

[7] Fecal coliforms will not be addressed in this section, because it is not a factor of decline for salmonids.

Tukwila (RM 13), Kent (RM 20) and Auburn (RM 27). The following conclusions were drawn from this study:

- The maximum summer temperatures in July and August were between 23.0 and 24.0°C at RM 12. The degree-hours value above 18.0°C (an indicator of the duration of elevated temperatures) was three times the value measured in the Middle Green (RM 41.5). Minimum temperatures at RM 12 during July and August were 15-16°C, comparatively high compared to most other stations;

- The maximum summer temperatures were 23.0 and 22.5°C at RM 20 and 27, respectively. The degree-hours value above 18.0°C were approximately 70 and 50 percent, respectively of the value at RM 12; and

- The study concluded that these temperatures were within the range where, according to some studies, salmonids would avoid this reach if possible. It was also concluded that there is potential for blockage or delay of upstream migration of adult anadromous salmon in August.

There were no other historic reports on water quality in the Lower Green River with the exception of the annual Metro water quality reports from the 1980s. The King County streams program has collected water quality data since 1970 at two stations on the lower Green River (0311, 3106).

WATER QUALITY – EXISTING CONDITIONS

The two locations for which data are available between 1996 and 1999 (Stations 0311 and 3106) are located near I-405 at approximately RM 12, where the land use is characterized by roadways, office and commercial development, Fort Dent Park and a golf course (see Figure WQ-1).

At station 0311, six parameters (temperature, DO, pH, turbidity, TSS and ammonia) were analyzed for 35 to 39 samples during nonstorm conditions and on one occasion during storm conditions on December 29, 1998. For station 3106, these same parameters were measured during both nonstorm (36 to 43 samples) and storm (12 to 14 samples) conditions. Additionally, total and dissolved metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) were analyzed at station 3106 during storm conditions on 13 and 7 occasions, respectively. Total and dissolved aluminum were analyzed on three and one occasions, respectively, during storm conditions. Comparisons of data to standards or criteria are detailed below.

Temperature

Based on King County's water quality data from 1996 through 1999, a number of temperature measurements for each location exceeded the Class A, proposed rearing and spawning standards (18, 17.5 and 14.5°C, respectively). Temperatures were never measured above the migration blockage threshold (21°C). The spawning threshold would not be applicable to these locations (approximately RM 12) because chinook and other salmonids are not known to spawn in this area. For chinook, most spawning is further upstream, between RM 24 to RM 61 (Williams et al. 1975). However, because several temperature measurements exceeded the Class A and rearing threshold, particularly during the mid- to late-summer, temperature may be of concern for salmonids in the Lower Green. It is important to note that temperature readings were only taken monthly and thus do not necessarily represent peak temperatures.

Dissolved Oxygen

Some DO concentrations for the two locations from 1996 to 1999 are below the Class A standard and proposed salmonid rearing standard (8.0 mg/L), and several measurements are below the proposed salmonid incubation standard (10.5 mg/L). Again, however, the incubation standard would not be applicable for these locations since salmonids are not known to spawn in this reach. Because six of the non-storm measurements were below the rearing threshold (ranging from 7.6 to 7.9 mg/L), there is some concern for salmonids during the summer months. Given that the solubility of oxygen in water is temperature dependent, it is not surprising to find dissolved oxygen exceedances co-located and concurrent with temperature exceedances.

Turbidity/TSS

Average non-storm turbidity is approximately 4 to 5 NTUs, with a peak storm turbidity measurement of 89 NTUs on December 28, 1998. Non-storm TSS concentrations averaged 8 to 11 mg/L for both locations during non-storm sampling, with a peak storm measurement of 114 mg/L during December 1998. A few measurements exceeded levels that could cause sub-lethal effects to salmonids if the concentrations were maintained for a long enough duration. However, the duration of these elevated TSS concentrations is unknown and therefore the potential effects cannot be determined. On average TSS does not appear to be of concern, though more data, including concentration and duration, is needed.

pH

Nearly all measurements evaluated in this analysis were between 6.5 and 8.1, a level at which there is not expected to be any direct effects on aquatic life (U.S. EPA 1986). The average pH was 7.0, however, five of 80 measurements were below the Class A standard of 6.5, with a minimum value of 6.2. Overall, pH is probably not a concern, though it may influence the potential toxicity of other chemicals (e.g., metals).

Ammonia

The ammonia data collected from 1996 to 1999 were below both the acute and chronic state water quality standards for ammonia. Therefore, ammonia is not expected to be of concern for salmonids.

Metals

Based on data collected from 1996 and 1999, metals (aluminum, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) do not seem to be a concern for salmonids, with the possible exception of aluminum.

Although there are no state water quality standards for aluminum, each of the three aluminum samples exceeded the EPA chronic water quality criterion (87 µg/L). One of the three samples

(1,540 µg/L), exceeded the EPA *acute* water quality criterion (750 µg/L). Although the limited data exceed the EPA criterion, it is not likely in a toxic form because the analytical method for determining total recoverable aluminum probably dissolves some aluminum that is not toxic and cannot be converted to a toxic form under natural conditions (U.S. EPA 1988). In addition, these data were collected under storm conditions where elevated suspended solids and organic matter concentrations tends to bind more of the dissolved metal, thereby reducing its bioavailability. However, because data are limited, further evaluations of aluminum should be conducted to confirm whether it is of concern for salmonids.

The same pattern for the basin as a whole is applicable to the Lower Green River data with regards to the detection limits for mercury and selenium (see section 4).

BIOLOGICAL MONITORING IN THE LOWER GREEN RIVER

Aquatic insect sampling occurred at one station on the mainstem in the lower Green River during 1999 (SalmonWeb 2000). The station was located at Lea Hill in Auburn at RM 28. The B-IBI score was 28, which is characterized as fair on the B-IBI index. This score is in the same range as those observed for the middle and upper Green River stations.

DATA GAPS

There are probably sufficient data to characterize temperature, DO, pH and ammonia at Stations 0311 and 3106; however, no other King County data between 1996 and 1999 were available for the lower Green River. Therefore, the spatial variability of these parameters in the lower Green River is a data gap. The lack of continuous temperature data is a data gap because data do not reflect daily maximum temperatures and the duration of temperature exceedances. In addition, there is no duration data available for TSS, thus the potential effects cannot be accurately evaluated. Furthermore, there are relatively few metals data (one to 16 samples), and nearly all were collected under storm conditions. Therefore, additional metals data are needed, especially under baseline (non-storm) conditions.

Other classes of parameters for which no data were available represent significant data gaps. No data were available for pesticides and herbicides, PAHs, or phthalate esters.

GREEN/DUWAMISH ESTUARY

The following description of the Duwamish River basin is summarized from the Combined Sewer Overflow Water Quality Assessment (WQA) for the Duwamish River and Elliott Bay (King County 1999). It is followed by a description of trends in Duwamish River since the 1960s, which is summarized from the draft Water Quality Trends report prepared by Pentec (2000). Finally, this is followed by a description of the existing water quality conditions, which includes some more recent data from the King County Streams Monitoring Program and compares it to both fresh and marine water quality standards, including the newly proposed use-based standards for temperature and DO.

The Duwamish River and Elliott Bay together make up a highly industrialized and urbanized estuary that has been extensively altered from its historic condition. The estuary is located on the eastern shore of Puget Sound and is surrounded by the City of Seattle. It is the location of heavy industry and a major shipping center as well as being home to a diverse array of fish, bird, mammal, and plant species. It is also used for tribal commercial and subsistence fishing and for recreation. Pollutants can enter the estuary from a variety of sources including industrial and commercial activities, storm drains, combined sewer overflows (CSOs), treatment plant emergency outfall, illegal dumping, atmospheric deposition, and groundwater.

The lower Duwamish River, from the river mouth to approximately 6 miles upstream from Harbor Island, is a highly industrialized salt wedge type estuary that is influenced by river flow and tidal effects. As is typical of salt wedge estuaries, the Duwamish is characterized by a sharp interface between freshwater outflow at the surface and saltwater inflow at depth. The layer of salt water is thicker near the river mouth, occupying most of the water depth, but tapers down toward the head (upriver portion) of the estuary. The location where saltwater intrusion tapers off to zero is called the toe of the salt wedge. In the Duwamish River the toe of the salt wedge is located approximately 11 miles upstream of the river mouth.

The lower portion of the river, below the turning basin (7 miles from the mouth) was straightened, dredged and armored with rocks in many areas to facilitate navigation and industrial development. The depth of the river portion varies from approximately 17 meters near the river mouth at Harbor Island to less than 1 meter in the upper river. Bottom sediments in the river range from sands to muds, depending on the sources of sediment and the current speeds. The flow of the river is largely controlled by releases from the Howard Hanson Dam. Summer flows in the river, gauged at Auburn, are in the range of 250 cubic feet per second (cfs). Winter flows average about 1,500 to 2,000 cfs, with peaks to more than 12,000 cfs as measured at the Auburn gage during storm events.

Over the last 125 years, the drainage area of the Duwamish River has been reduced by about 70 percent due to development and flow diversion. Most (98 percent) of approximately 1,270 acres of tidal marsh and 1,450 acres of flats and shallows, and all of about 1,250 acres of tidal wetland, have been eliminated (Blomberg et al. 1988). The intertidal habitat that remains in the Duwamish River is important for the survival of juvenile salmon, other predator fish, birds, and mammals that feed on invertebrates and small fish found in shallow areas of the estuary. Kellogg Island is the largest remnant of intertidal habitat remaining in the Duwamish River Estuary (Tanner 1991). Habitat associated with the island includes high and low marsh, intertidal flats, and filled uplands (Canning et al. 1979). Kellogg Island provides important nesting and feeding habitat for waterfowl and other birds. Small patches of other intertidal areas occur in the estuary as marsh and unvegetated intertidal benches. Sections of natural shoreline only occur in the Duwamish River above the head of navigation, located at approximately River Mile 6 (Tanner 1991).

WATER QUALITY TRENDS IN THE DUWAMISH RIVER[8]

Overall, water quality in the Duwamish estuary was probably poorest in the early 1960s. Since the 1980s, however, water quality impacts from the discharge of industrial and domestic waste have been significantly reduced as a result of increased surveillance monitoring and the construction of the wastewater effluent transfer line. The removal of the South (Renton) Treatment Plant outfall led to significant decreases in the ammonia and phosphorus

[8] Summarized from the draft Water Quality Trends report prepared by Pentec (1999)

concentrations in the Green River. Temperature, turbidity, and nitrate levels have decreased significantly, and DO and pH have increased (King County 1989).

In the 1940s and 1950s, there were a large number and wide variety of direct point-source discharges to the Duwamish River (e.g., Foster 1945, Sylvester et al. 1949, Peterson et al. 1955). These discharges included metal wastes from foundaries, shipyards, and aircraft manufacturing operations; chemical wastes from a variety of industries; blood and paunch manure from meat-packing plants; vegetable wastes; fish packing wastes; concrete and clays; and domestic sewage.

Temperature, bacteria, nutrients, and oxygen levels historically created biological problems in the Duwamish River (Ecology 1988). Levels of metals and/or other pollutants were sufficient to cause fish kills as early as 1948 (Fasten 1948), and as recently as 1985 (possibly from low DO; L. Kittle, Washington State Department of Ecology, personal communication in Grette and Salo 1986).

The following presents a description of water quality trends in the Duwamish River. These trends are based on temperature, DO, and metals water quality data, most of which have been collected by King County (Metro) at 17 stations throughout the Duwamish River since the 1970s. Three stations have the most complete data set over the last 40 years: the West Waterway Spokane Street Bridge (station 0305 at RM 1/4), 16th Avenue Bridge (station 0307 at RM 3.5), and the East Marginal Way Bridge (station 0309 at RM 6.75) [9].

Temperature

Since 1970, temperature has been recorded monthly at stations 0305, 0307, and 0309. These stations have seen an overall increase of maximum temperatures of approximately 2°C since the 1970s (Figure WQ-5, Pentec 1999). The frequency of freshwater temperature criterion exceedances has increased from one in the 1970s to three in the 1980s, and seven from 1990 to 1998. The frequency of marine water temperature criterion exceedances has increased from 3 in the 1970s to 13 in the 1980s, and 15 from 1990 to 1998. However, due to sampling depths (0.5 m) and location of stations 0307 and 0309, the freshwater water criterion is more applicable. Using the freshwater criterion for the 16th Avenue and East Marginal Way bridge stations, and the marine criterion at the West Waterway Spokane Street Bridge station, there was one exceedance in the 1970s, three in the 1980s, and six in the 1990s (through 1998).

Dissolved Oxygen

During the mid-1950s, the Washington State Pollution Control Commission (Peterson et al. 1955) conducted sanitary-quality surveys in the Green and Duwamish rivers, collecting data on bacteriological character, DO, BOD, and toxic compounds. They sampled DO through the summer and fall of 1955 and found two instances of values below 5 mg/L. The authors concluded that the DO levels in the Duwamish River were satisfactory but noted that river flows were unusually high and temperatures unusually low during that year.

In the 1960s, Santos and Stoner (1972) conducted a study of physical, chemical, and biological aspects in the Duwamish Estuary at four locations. They concluded that the DO in the surface

[9] Class B standards for temperature and DO are applied in the following discussion.

water decreased in a downstream direction, but usually contained enough oxygen to support aquatic life. Minimum DO values occurred in late summer in the bottom layer, and ranged from 7.7 mg/L to 10.4 mg/L. However at low rates of freshwater inflow and minimal tidal exchange, DO was reported as low as 1 mg/L in the 1960s (Metro 1985). Comparing older data with the data collected during their study, Santos and Stoner suggested that a slight decrease in the annual minimum DO concentrations had occurred from 1960 to early 1970.

Completion of the Howard Hanson Dam in 1962 provided low-flow augmentation during the summer months and helped offset, to a degree, increases in sewage discharges from the expanding population of the watershed (US Army Corps of Engineers 1997). The East and West Marginal interceptors were constructed by Metro in 1964 and 1967, respectively, allowing industrial discharges to be removed from the Duwamish and diverted to the West Point Treatment Plant (Metro 1985). In 1965, the Diagonal Way sewage treatment plant was closed and the sewage was diverted to West Point. The South (Renton) Treatment Plant was also constructed in 1965. The Kent and Auburn sewage lagoons were discontinued in 1973 and 1977, respectively, and the sewage was diverted to the South (Renton) Treatment Plant. With the removal of these two effluent discharges to the Green River system, the South Treatment Plant became the only municipal point source of effluent to the Duwamish (Metro 1985).

The South (Renton) Treatment Plant discharge adversely affected water quality by depressing DO levels and increasing levels of nutrients and ammonia beyond EPA guidelines. Diversion of the Plant's outfall to a new deepwater diffuser in Puget Sound in 1987 produced marked improvements in water quality in the Duwamish Estuary. These improvements resulted in marked increases in the minimum DO in the estuary.

Trends from stations 0305, 0307, and 0309 show that the annual minimum DO has been increasing since the 1970s, and that there was a jump in the rate of increase in the mid-1980s, corresponding to the diversion of the South Treatment Plant discharge. As a result, low DO levels and resulting mortalities or delays in upstream migrations of chinook, which used to occur frequently in the Duwamish (Salo 1969; Grette and Salo 1986), have not been reported since this diversion.

Metals

Beginning in the 1970s, enforcement of the Clean Water Act and implementation of National Pollutant Discharge Elimination System (NPDES) prohibitions against discharge of toxic or deleterious materials markedly reduced point-source discharges, from municipal and industrial sources, to the Green/Duwamish River and Estuary. From 1981 to 1988, almost 2.4 billion gallons of untreated sewage and stormwater were discharged from combined sewer overflows (CSOs) to the Duwamish Estuary and Elliott Bay, Lake Washington and Ship Canal. Since 1989, the volume of untreated sewage and stormwater discharged from CSOs to these receiving waters has been reduced to 1.8 billion gallons per year (King County 1999).

The combination of these controls of point-source discharges, and increased emphasis on stormwater controls and associated best management practices have greatly improved water quality conditions in the Duwamish. For example, the Pacific Marine Environmental Laboratory monitored the Duwamish River from 1981 to 1986 and showed dramatic decreases of copper, lead, and zinc concentrations in the water. In 1986, dissolved lead discharges into the Duwamish River were only one percent of the amount discharged in 1981; dissolved copper and zinc discharges were only five and 10 percent, respectively, of amounts discharged in 1981 (King County 1989).

The result of all of the controls implemented in the 1970s and 1980s on levels of many toxicants was dramatic, as shown in the marked drops in levels of several metals in the lower Duwamish River. In most cases, levels of cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc, which were often above toxic thresholds in the early 1980s, have dropped below the State’s chronic water quality standards (173-201A WAC).

In summary, it is clear that water quality conditions in the Duwamish Estuary today are much improved over conditions from the 1940s through the mid-1980s. During the period from 1970 to the present, water quality, with the exception of temperature, has shown a clear trend of improvement in virtually all measured parameters. An assessment of current water quality is presented in the following two sections.

DUWAMISH RIVER AND ELLIOTT BAY WATER QUALITY ASSESSMENT

In 1996, the King County Department of Natural Resources (King County 1999) studied the existing conditions in the Duwamish, as well as the County’s combined sewer overflows (CSOs) and their effects on water quality in the Duwamish River using a risk assessment approach. The risk assessment looked at several receptors, including aquatic life, benthos, shorebirds, wading birds, raptors, mammals, and humans. The study investigated several chemicals in water and in sediment, physical disturbances, and changes in salinity, DO, pH, and water temperature (King County 1999).

Overall, the Water Quality Assessment (WQA) found minimal risks to aquatic life from chemicals in the water column, no risk of mortality to juvenile salmon from direct exposure to chemicals in the water, and no risk of mortality to salmon smolt from consuming amphipods in the Duwamish Estuary. More specifically, the study found the following:

- Risks to water column dwelling organisms, from exposure to chemicals of potential concern in the water of the Duwamish River and Elliott Bay, appear to be minimal. Any potential risks are below the level used by U.S. EPA to develop water quality criteria. These predicted risk levels were confirmed by the observed lack of chronic toxicity to sensitive organisms from undiluted effluent from the Brandon Street CSO.

- There was no apparent risk of mortality to salmon from exposure to chemicals in the water column.

- There was no apparent risk of mortality to salmon from concentrations of copper, lead, zinc, tributyltin (TBT) or polychlorinated biphenyls (PCBs) (Aroclors 1254 and 1260) in their prey. Other chemicals were not evaluated because of a lack of appropriate data.

The WQA found potential risks to the benthic community from several chemicals in the sediments, most notably bis(2-ethylhexyl)phthalate, 1,4-dichlorobenzene, mercury, polycyclic aromatic hydrocarbons (PAHs), PCBs, and TBT. PCBs and TBT were found to pose the greatest potential risks to benthic organisms.

WATER QUALITY—EXISTING CONDITIONS

The Duwamish River is listed on the State's 303(d) list of impaired water bodies for multiple sites and parameters. Although water in the Duwamish River is only listed for exceeding pH, fecal coliforms and DO standards, sediments exceed standards for numerous chemicals including a variety of metals, PAHs, PCBs, phthalate esters and phenol.

Recent King County data were available for a total of 19 stations in the Duwamish River. Sixteen of these stations were sampled from nine sites in 1996 and 1997 for the Duwamish River and Elliott Bay WQA, and represent either east bank, center channel or west bank sampling within the Duwamish River channel at six sites (CSO locations). At each station, samples were collected both one meter under the surface and one meter above the bottom (or at 20 meters depth if bottom depth was greater than 20 meters). Table WQ-6 below describes the site abbreviations used for the Duwamish River WQA, and sampling locations are depicted in FigureWQ-1.

Table WQ- 6. Site abbreviations from the Duwamish River WQA.

Site	East Bank (1,2)	Center Channel (1,2)	West Bank (1,2)
Norfolk		NFKBLB	
S/W Michigan	SWM/E	SWM/C	SWM/W
Brandon	BRN/E	BRN/C	BRN/W
Chelan	CHE/E	CHE/C	CHE/W
Hanford	HNF/E	HNF/C	HNF/W
Connecticut	HNF/E	HNF/C	HNF/W

1 = surface and 2 = depth (e.g., SWM/E1 and SWM/E2).

Data are also available between 1996 and 1999 for three other stations sampled as part of the Streams Monitoring Program (0305, 0307, 0309). These stations are also depicted in Figure WQ-1. Table WQ-7 summarizes the number of samples analyzed for each parameter at all locations in the Duwamish River (WQA and Streams Monitoring Program) between 1996 and 1999.

Table WQ-7. Number of Non-storm and Storm Samples Collected in Duwamish (1996-99).				
Parameter	**Non-storm**	**Storm**	**# of Stations**	**# of Sites**
Arsenic, Dissolved	272	90	31	6
Cadmium, Dissolved	272	88	31	6
Chromium, Dissolved	242	80	31	6
Chromium, Total	521	286	31	6
Copper, Dissolved	254	90	31	6
Lead, Dissolved	264	90	31	6
Mercury, Dissolved	33		7	4
Mercury, Total	63		31	6
Nickel, Dissolved	246	90	31	6
Nitrogen, Ammonia	810	302	36	9
Oxygen, Dissolved	571	212	35	8
Pentachlorophenol	114	88	30	5
pH	817	302	36	9
Selenium, Dissolved	262	82	31	6
Selenium, Total	526	258	31	6
Silver, Dissolved	272	90	31	6
Solids, Suspended, Total	1479	599	36	9
Temperature, Sample	841	296	36	9
Turbidity	149	5	5	3
Zinc, Dissolved	272	87	31	6

Temperature

Based on the water quality data collected between 1996 and 1999, all temperature measurements were below the migration blockage threshold (21°C) and the Class B marine standard (19°C) at all stations except 0307 and 0309. At station 0307, five of 55 surface (0-1 m) temperature measurements exceeded the Class B marine standard, with a maximum of 20.4°C; no exceedances were measured at depth. At station 0309, five of 38 temperature measurements exceeded the Class B marine standard and one of those exceeded the migration blockage threshold, with a maximum of 21.7°C. These data suggest that peak summer temperatures may be of concern for salmonids rearing in or migrating through the upper reach of the Duwamish River. It is important to note that temperature readings were only taken monthly and thus do not necessarily represent peak temperatures.

Dissolved Oxygen

A total of 783 DO measurements were taken at the Duwamish River stations between 1996 and 1999. At Station 0305, two DO measurements were below the Class B marine standard (5 mg/L), with a minimum of 4 mg/L. These data suggest that DO concentrations may be of concern for salmonids rearing in the Duwamish River.

Turbidity/TSS

Turbidity data were only available at three stations within the Duwamish River, with between 37 and 59 measurements at stations 0305, 0307 and 0309. Average turbidity measurements (both surface and depth) ranged from 2.0 to 6.4 NTUs during non-storm conditions, with a maximum of 24 NTUs. Storm turbidity measurements at these locations ranged from 14 to 92 NTUs.

Between 37 and 66 samples were measured for TSS at all sampling stations within the Duwamish River, except at NFKBLB, where only three samples were collected. Average non-storm TSS ranged from 3.6 to 19.3 mg/L, and average storm TSS ranged from 13.7 to 22.4 mg/L at all stations except 0305, 0307 and 0309. Only one or two storm samples were collected at each of these three stations, and measurements ranged from 23.6 to 122 mg/L. These data suggest that TSS concentrations in the Duwamish River occasionally exceeded levels that could cause sub-lethal effects, especially during storm conditions, if the concentrations were maintained for a long enough duration. However, the duration of the elevated TSS concentrations is unknown, and therefore, potential effects cannot be determined. More data, including concentration and duration, are needed.

pH

Between 30 and 60 pH measurements at each sampling station were recorded between 1996 and 1999. All pH measurements were between the Class B marine standards of 7.0 to 8.5 at all stations except BRN/E1, 0305, 0307 and 0309. One of 32 measurements station BRN/E1 and one of 59 measurements at station 0305 was below 7.0, with a minimum of 6.9 for each. At station 0307, four of 60 measurements were below 7.0, with a minimum of 6.8, and one measurement was 8.6. At station 0309, 10 of 38 measurements were below 7.0, with a minimum of 6.3. However, given that no adverse effects to salmonids are expected at pH levels between 6.5 and 9.0 (U.S. EPA 1976), and that only one of the total of 1119 pH values was below 6.3, pH is not likely to be a factor of decline for salmonids, although it may influence the potential toxicity of other chemicals (e.g., metals).

Ammonia

The ammonia data collected from 1996 to 1999 were below both the acute and chronic state water quality standards for ammonia. Therefore, ammonia is not expected to be of concern for salmonids.

Metals

Based on the data collected by King County and MIT from 1996 to 1999, the metals evaluated here (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) suggest that they are not of concern.

Organic Chemicals

The pentachlorophenol data collected in 1996 and 1997 for the Duwamish River and Elliott Bay WQA were below both the acute and chronic state marine water quality standards. Therefore, pentachlorophenol is not expected to be of concern for salmonids. No other King County data for organic chemicals with standards or criteria developed were available.

CRISP CREEK

The Crisp Creek subbasin is a small tributary to the Green River located just west of the City of Black Diamond. The basin is approximately 4.5 square miles in area and flows into the Green River at river mile 40. Crisp Creek drains flat to gently rolling terrain in the upper portion of the watershed then drops steeply from the plateau through the valley walls of the Green River before flattening out in the alluvial valley. The entire basin is located in unincorporated King County in the rural zone, mostly consisting of pre-existing one, 2.5 or 5-acre lots or in current 5-acre zoning.

Crisp Creek is not listed on the state's 303(d) list of impaired water bodies. A Water Quality and Quantity Concerns report was completed for the Crisp Creek watershed because of concerns about impacts on operation of the Muckleshoot Tribe's Keta Creek Hatchery (Muckleshoot Indian Tribe 1992). This report identifies risks to fish resources, water quality, and water quantity, but no water quality data are presented. The report identifies the planned and potential conversion of forested lands to residential developments as the greatest risk to water quality.

WATER QUALITY—EXISTING CONDITIONS

King County has collected data from two locations on Crisp Creek as part of its Stream Monitoring Program. Station F321 is located immediately upstream of the Keta Creek Hatchery, and Station 0321 is within one mile downstream of the hatchery (see Figure WQ-2).

At station 0321 and F321, six parameters (temperature, DO, pH, turbidity, TSS and ammonia) were analyzed in 38 to 46 samples during nonstorm conditions between 1996 and 1999. These same parameters were measured during storm conditions on 15 to 17 occasions. Additionally, total and dissolved metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) were analyzed at station 0321 during storm conditions on roughly 17 and 11 occasions, respectively. Total and dissolved aluminum were analyzed on three and one occasions, respectively, during storm conditions. Comparisons of data to standards or criteria are detailed below.

Temperature

Continuous water temperature data were collected at the King County stream gauge near the mouth of Crisp Creek (station 40D) from October 1997 to September 1999 (water years 1998 and 1999). The maximum recorded daily temperature during this period was 20°C on five days in July and August 1998. During the two year period, the Class A standard of 18°C and the proposed 17.5°C rearing standard were exceeded on 12 and 17 days, respectively, in July and August 1998. The proposed 14.5°C spawning standard (September 15 to May 31) was exceeded on seven days in late September 1998 (maximum of 16°C) and two days each in late May 1998 and 1999 (maximum of 17°C in 1998).

The proposed rearing standard of 15°C for the moving 7-day average of the daily maximum temperatures was not exceeded during water year 1999, but was exceeded on 69 days during water year 1998 from early July to mid-September. The maximum 7-day average was 18.7°C. The proposed spawning standard of 12°C for the moving 7-day average of the daily maximum temperatures (September 15 to May 31) was exceeded on 13 days in April and May of 1999 (maximum of 14°C) and 15 days in late September 1999 (maximum of 13°C). In water year 1998, the spawning standard was exceeded on nine, 23, and 15 days in October 1997, May and September 1998, respectively. The maximum was 14.7°C in September 1998. These data suggest that temperature is a possible factor of decline for salmonids in Crisp Creek, based on occasional exceedances of the Class A standard and somewhat frequent exceedances of the proposed rearing and spawning standards of from 1 to 3°C.

Dissolved Oxygen

Based on the available water quality data collected between 1996 and 1999, DO concentrations at either location were always greater than the minimum Class A and proposed salmonid rearing standard (8.0 mg/L). However, 22 of 50 DO measurements at station 0321 were below the incubation standard (10.5 mg/L) during the potential salmonid incubation period (September 15 to May 31), with a minimum value of 8.3 mg/L. At station F321, one DO value in October was 10.4 mg/L, but all other measurements were greater than 10.5 mg/L. Therefore, DO may be of concern for salmonids below the Keta Creek Hatchery.

Turbidity / TSS

Based on the available water quality data from 1996 through 1999, average non-storm and storm turbidity was 2.5 and 3.5 NTUs, respectively. The maximum turbidity was 13 NTUs. Geometric mean non-storm and storm TSS was 5 and 7 mg/L, respectively, with a maximum concentration of 48.5 mg/L. The next highest recorded measurement was 17.4 mg/L. Therefore, at least one measurement exceeded levels that could cause sub-lethal effects if the concentration was maintained for a long enough duration. However, the duration of the elevated TSS concentration is unknown and therefore, potential effects cannot be determined. On average, TSS does not appear to be of concern for salmonids, although more data, including concentration and duration, are needed to be more certain.

pH

Based on the available data from 1996 through 1999, pH is always between 6.6 and 8.1. This range is not expected to elicit any direct effects to aquatic life, and therefore, pH is unlikely to be of concern for salmonids in Crisp Creek, although it may influence the potential toxicity of other chemicals (e.g., metals).

Ammonia

The ammonia data collected from 1996 to 1999 were below both the acute and chronic state water quality standards for ammonia. Therefore, ammonia is not expected to be of concern for salmonids.

Metals

The metals evaluated at station 0311 (aluminum, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) are not of concern for salmonids, with the possible exception of aluminum. Although there are no state water quality standards for aluminum, two of the three aluminum samples exceeded the EPA chronic water quality criterion (87 µg/L).

Although the limited data exceed the EPA criterion, it is not likely in a toxic form because the analytical method for determining total recoverable aluminum probably dissolves some aluminum that is not toxic and cannot be converted to a toxic form under natural conditions (U.S. EPA 1988). In addition, these data were collected under storm conditions where elevated suspended solids and organic matter concentrations tends to bind more of the dissolved metal, thereby reducing its bioavailability. However, because data are limited, further evaluations of aluminum should be conducted to confirm whether it is of concern for salmonids.

The same pattern for the basin as a whole is applicable to the Crisp Creek data with regards to the detection limits for mercury and selenium (see section 4).

DATA GAPS

There are probably sufficient data to characterize temperature, DO, pH and ammonia conditions in Crisp Creek. Available TSS data do not include information on duration, without which potential effects cannot be accurately evaluated. Furthermore, although there are adequate metals data at station 0321, all were collected under storm conditions. Therefore, additional metals data are needed to describe baseline (non-storm) conditions, especially for aluminum. There are no metals data available at station F321.

Other classes of parameters for which no data were available represent significant data gaps. No data were available for pesticides and herbicides, PAHs, or phthalate esters.

NEWAUKUM CREEK

The Newaukum Creek subbasin is located in southeast King County near the City of Enumclaw. The basin is over 27 square miles in area and flows into the Green River at river mile 40.7 (see Figure WQ-2). Extensive water quality sampling has been carried out in the subbasin since 1995 by the Muckleshoot Indian Tribe Fisheries Department and the King County Department of Natural Resources (Wachter 1999).

The headwaters of Newaukum Creek begin at an elevation of 5,000 feet near Boise Ridge and are dominated by forest activities. The middle subbasin, the Enumclaw plateau, consists mostly of agricultural activities and is relatively flat. The lower subbasin consists of a steep ravine and descent to the Green River. Land uses in the middle and lower subbasins include dairy and cattle farming, and rural residential development (Wachter 1999). The southern portion of the middle subbasin also contains the City of Enumclaw. In the agricultural areas, extensive ditching has occurred for stormwater conveyance and field application of manure and fertilizers is common. Salmonids present in this subbasin include coastal cutthroat, chinook, coho, winter steelhead, sockeye and chum.

Four reaches along Newaukum Creek are listed on the state's 303(d) list of impaired water bodies for failing to meet state surface water standards. All four reaches are listed for fecal coliforms. One reach is also listed for DO and another reach is listed for ammonia. Since the results reported by Wachter (1999) are based on the King County and MIT streams data collected from 1995 to 1997, which overlaps with the existing data from 1996 to 1999, no results from that report are summarized here.

WATER QUALITY—EXISTING CONDITIONS

King County and the MITFD collected data from 18 locations on Newaukum Creek as part of the Stream Monitoring Program (Figure WQ-2) between 1996 and 1999. Extensive sampling during baseflow and storm conditions occurred at station 0322, located approximately one mile upstream of the confluence with the Green River. Table WQ-8 summarizes the number of samples analyzed for each parameter at each of the other 17 locations during storm and nonstorm conditions between October 1996 and December 1999.

Table WQ-8. Summary of Number of Samples Analyzed from October 1996 to December 1999 for Each Parameter in the Newaukum Creek Basin.

Sampling Station	Non-storm/storm	Nitrogen, Ammonia	DO	pH	TSS	Temp	Turbidity
AA322	N	9	9	8	9	9	9
	S	2	2	1	2	2	2
AB322	N	11	11	9	11	11	11
	S	3	3	2	3	3	3
AC322	N	10	10	8	10	10	10
	S	2	2		2	2	2
AD322	N	11	11	9	11	11	11
	S	2	4		2	2	2
AE322	N	10	11	8	10	10	10
	S	3	3	2	3	3	3
AF322	N	10	10	8	10	10	10
	S	2	2	1	2	2	2
AG322 / M322	N	18	18	8	19	19	19
	S	3	3	1	3	3	3
AH322	N	10	10	7	10	10	10
	S	2	2	1	2	2	2
AI322 / P322	N	33	35	7	34	34	34
	S	4	4	1	4	4	4
AJ322	N	9	9	7	9	9	9
	S	2	2	1	2	2	2
D322	N	35	41		36	37	36
	S	2	2		2	2	2
F322	N	34	37	7	35	36	35
	S	3	3	1	3	3	3
H322	N	36	39	9	37	38	37
	S	4	5	1	4	4	4
J322	N	35	36	9	36	37	36
	S	3	3	1	3	3	3
K322	N	22	23		23	24	23
N322	N	34	42	7	35	36	35
	S	3	3	1	3	3	3
T322	N	35	41		36	36	36
	S	2	2		2	2	2
Note: Some stations had more than one identifier during the study period (1996-99).							

At station 0322, five parameters (temperature, DO, turbidity, TSS and ammonia) were analyzed in 71 to 76 samples during nonstorm conditions between 1996 and 1999. Measurements of pH were made for 36 samples during nonstorm conditions. All six parameters were measured during storm conditions on 13 to 16 occasions. Additionally, total and dissolved metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) were analyzed at station 0322 during storm conditions on roughly 13 and 7 occasions, respectively. Total aluminum was analyzed on three occasions during storm conditions. Comparisons of data to standards or criteria are detailed below.

Temperature

No continuous temperature data were available for Newaukum Creek. Based on the available water quality data from 1996 though 1999, temperatures were always below the migration blockage threshold (21°C), the Class A standard (18°C), and the proposed salmonid rearing standard (17.5°C). However, a number of individual measurements exceeded the proposed spawning standard (14.5°C) during the summer, with a maximum of 15.5°C. These exceedances do not coincide with the spawning of fall chinook. In addition, the proposed spawning standard would not apply to the period when exceedances were measured (Hicks 2000a). This suggests that temperature is not a factor of decline for chinook salmon in Newaukum Creek; however, temperature readings are only taken monthly and do not necessarily represent peak temperatures during the spawning season. Given that spawning standards were exceeded in the summer, temperature may be of concern for any salmonids (e.g., winter steelhead) that spawn or incubate during summer months.

Dissolved Oxygen

As noted above, DO is listed on the State's 303(d) list of impaired water bodies for failing to meet state surface water standards for one segment of Newaukum Creek. This listing is based upon data collected at RM 10.1 at the confluence with Stonequarry Creek. Between 1991 and 1997, eight of 15 samples at this location were below the state standard. Based on the available water quality data from 1996 through 1999, all DO concentrations are greater than the minimum Class A and proposed salmonid rearing standard at all sampling locations except for D322 and AC322. At D322, 12 of 41 measurements were below 8.0 mg/L with a minimum of 5.9 mg/L, and at AC322, five of 10 DO concentrations were below 8.0 mg/L, with a minimum of 5.8 mg/L. Therefore, when evaluating individual DO readings, the recent data support the listing because water quality standards are still exceeded.

When comparing these data to the proposed salmonid incubation standard, there were individual measurements below 10.5 mg/L at all locations, except AJ322. In addition, all sampling locations had DO concentrations below the proposed spawning standard during the defined spawning season (September 15th through May 31st) between 1996 and 1999. Therefore, DO is probably of concern for salmonids in Newaukum Creek.

Turbidity / TSS

Based on the available water quality data from 1996 through 1999, average non-storm turbidity ranged from 1.4 to 5.8 NTUs, with a maximum value of 15 NTUs. The storm turbidity data ranged from 0.6 to 51 NTUs, although only seven of 58 storm turbidity measurements were greater than 20 NTUs.

Average non-storm TSS ranged from 1.2 to 10.7 mg/L, with peak measurements as high as 95.6 mg/L. Although these were not classified as storm samples, these peak measurements likely occurred shortly after a storm event or some other disturbance (such as maintenance activities) that caused a short-term increase in TSS. Storm TSS measurements ranged from 0.6 to 120 mg/L, indicating that TSS concentrations occasionally exceeded levels that could cause sub-lethal effects if the concentrations were maintained for a long enough duration. However, the duration of the elevated TSS concentrations is unknown, and therefore, potential effects cannot be determined. On average, TSS does not appear to be of concern, although more data, including concentration and duration, are needed.

pH

Based on the available data from 1996 through 1999, pH was between 6.5 and 8.5 at all sampling locations except AA322 and AD322. At AA322, two of nine measurements were 8.6. Given that the magnitude of the exceedance is within the tolerance limits of the instrument used to measure it, pH at AA322 is not expected to elicit any direct effects to aquatic life. At AD322, one of nine measurements was 9.8. If this datum was representative of the creek, pH would likely have adverse effects on aquatic life. However, given that 177 of the 178 pH measurements in Newaukum Creek were within 6.5 to 8.6, this value is probably an anomaly or resulted from equipment malfunction. Therefore, pH is not likely a concern for salmonids, although it may influence the potential toxicity of other chemicals (e.g., metals).

Ammonia

One segment of Newaukum Creek, just upstream of station 0322, is listed on the State's 303(d) list of impaired water bodies for failing to meet the state surface water ammonia standard. This listing is based upon three excursions beyond the standard collected between 1991 and 1997 at RM 2.1. Based on the available water quality data from 1996 through 1999, ammonia never exceeded either its acute or chronic water quality standard; therefore, ammonia is not likely a concern for salmonids.

Metals

The metals evaluated here (aluminum, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) suggest that they are not of concern, with the possible exception of aluminum. Although there are no state water quality standards for aluminum, all three aluminum samples at station 0322 exceeded the EPA chronic water quality criterion (87 µg/L). Two of the three samples exceeded the EPA *acute* criterion (750 µg/L). Although the limited data exceed the EPA criterion, it is not likely in a toxic form because the analytical method for determining total recoverable aluminum probably dissolves some aluminum that is not toxic and cannot be converted to a toxic form under natural conditions (U.S. EPA 1988). In addition, these data were collected under storm conditions where elevated suspended solids and organic matter concentrations tends to bind more of the dissolved metal, thereby reducing its bioavailability. However, because data are limited, further evaluations of aluminum should be conducted to confirm whether it is of concern for salmonids.

The same pattern for the basin as a whole is applicable to the Newaukum Creek data with regards to the detection limits for mercury and selenium (see section 4).

DATA GAPS

There are probably sufficient data to characterize temperature, DO, pH, turbidity and ammonia in Newaukum Creek. The lack of continuous temperature data is a data gap because data do not necessarily reflect daily maximum temperatures and the duration of temperature exceedances. Similarly, available TSS data do not include duration, without which potential effects cannot be accurately evaluated. Furthermore, although there are adequate metals data at station 0322, all were collected under storm conditions. Therefore, additional metals data are needed to describe baseline (non-storm) conditions, especially for aluminum. There were no metals data available for other sampling locations in Newaukum Creek.

Other classes of parameters for which no data were available represent significant data gaps. No data were available for pesticides and herbicides, PAHs, or phthalate esters.

SOOS CREEK

The Soos Creek subbasin lies north and east of the Green River and southeast of Renton and east of Kent. The Soos Creek system drains an area of 70 square miles and consists of several streams including Big Soos, Little Soos, Soosette, Covington, and Jenkins. All major tributaries in the subbasin have similar physical characteristics, draining flat to rolling terrain and converging below river mile 5.0 of Big Soos Creek. Many reaches of the upper plateau flow through extensive wetlands where pools are deep and velocities slow. There are also numerous lakes in the Soos Creek subbasin, including Lake Youngs, Lake Meridian, Shadow Lake, Lake Sawyer, Lake Wilderness, Pipe Lake/Lake Lucerne, Ginger Lake, Ravensdale Lake, and Lake Morton.

Most of the Soos Creek basin is developed as either urban or rural land uses. The north and west portions of the basin have a pattern of high-density residential and commercial development. The north portion of Jenkins Creek and the west portion of Covington Creek contain rural residential areas consisting of small farms and pastures. Sand, gravel and clay are mined in the hills east and northeast of Black Diamond, and coal is mined near the northeast corner of Ginger Lake.

Ten reaches within the Soos Creek basin are listed on the state's 303(d) list of impaired water bodies for failing to meet state surface water standards. Nine reaches are listed for fecal coliforms, three reaches are listed for dissolved oxygen and one reach is listed for temperature. In addition, Lake Meridian is listed for total phosphorus.

There were no historic reports on water quality in the Soos Creek basin with the exception of the annual Metro water quality reports from the 1980s. The King County streams program has collected water quality data since 1976 at five stations in the Soos Creek basin on Covington, Jenkins, Soosette, Big Soos and Little Soos creeks.

WATER QUALITY—EXISTING CONDITIONS

King County and the Muckleshoot Indian Tribe have collected data from 17 locations in the Soos Creek subbasin as part of the Streams Monitoring Program: five locations on Big Soos Creek, three on Little Soos Creek, one on Jenkins Creek, and four on both Covington Creek and Soosette Creek (see Figure WQ-1). The number of samples analyzed for each parameter at each location between 1996 and 1999 during non-storm and storm conditions is given below.

Storm samples were analyzed for six parameters (temperature, pH, DO, turbidity, TSS and ammonia) on two occasions at stations C320, D320, G320, and L320 and on one occasion at stations B320, Q320, R320, S320 and U320. Non-storm sampling occurred for these same six parameters on 35 to 55 occasions at three stations in Big Soos Creek (A320, L320, N320), two stations in Little Soos Creek (G320, U320), three stations in Covington Creek (C320, R320, S320), and one station each in Jenkins Creek (D320) and Soosette Creek (B320). Non-storm sampling occurred on 19 to 27 occasions at two stations in Big Soos Creek (M320, P320) and three stations in Soosette Creek (V320, X320, Y320), on 15 to 17 occasions at station T320 in Little Soos Creek and 10 to 11 occasions at Q320 in Big Soos Creek.

Temperature

One segment of Little Soos Creek is listed on the State's 303(d) list of impaired water bodies for failing to meet the temperature standards. The listing of Little Soos Creek is based on seven excursions measured between 1991 and 1997 at sampling station T320 (RM 3.2). Continuous temperature data were collected between 1996 and 1999 for most subbasins. Different water years are available for five locations in the basin for Big Soos, Little Soos, Jenkins, Covington, and Soosette creeks.

Big Soos Creek

Continuous water temperature data were collected at the King County stream gauge near the mouth of Big Soos Creek (station 54A) from October 1997 to September 1999 (water years 1998 and 1999). The maximum recorded daily temperature during this period was 21.7°C in late July 1998. During the two-year period, the Class A standard of 18°C and the proposed 17.5°C rearing standard were exceeded on 28 and 40 days, respectively in 1998, and on 11 and 20 days, respectively in 1999, between mid-May and September. The proposed 14.5°C spawning standard (September 15 to May 31) was exceeded on seven days from late April to late May 1998 (maximum of 17.1°C) and eight days in late September 1998 (maximum of 15.6°C). During 1999, it was exceeded on eight days from mid-April to late May (maximum of 18.1°C) and four days in late September (maximum of 15.3°C).

The proposed rearing standard of 15°C for the moving 7-day average of the daily maximum temperatures was exceeded on 68 and 104 days in 1998 and 1999, respectively, from late May to mid-September (maximums were 20.0 and 17.3°C). The proposed spawning standard of 12°C for the moving 7-day average of the daily maximum temperatures (September 15 to May 31) was exceeded on 11 and 13 days in October 1997 and 1998, respectively (maximum of 13.5 and 12.6°C), 38 and 21 days in mid-April to late May 1998 and 1999, respectively (maximum of 15.4 and 16.0°C) and 16 days during late September in both 1998 and 1999 (maximum of 15.7 and 14.6°C). These data suggest that temperature is a probable factor of decline for salmonids in Big Soos Creek. This is based on somewhat frequent exceedances of the Class A and proposed rearing and spawning standards (both maximum and the moving 7-day averages) of from 1 to 4°C.

Little Soos Creek

Continuous water temperature data were collected at the King County stream gauge near the mouth of Little Soos Creek (station 54I) from October 1998 to September 1999 (water year 1999). The maximum recorded daily temperature during this period was 21.7°C in mid-June 1999. During the one-year period, the Class A standard of 18°C and the proposed 17.5°C rearing standard were exceeded on 62 and 71 days, respectively, between mid-May and September. The proposed 14.5°C spawning standard (September 15 to May 31) was exceeded on five days in October 1998 (maximum of 16.3°C), 14 days in mid-April to late May 1999 (maximum of 19.4°C), and 11 days in late September 1999 (maximum of 18.3°C).

The proposed rearing standard of 15°C for the moving 7-day average of the daily maximum temperatures was exceeded on 124 days from late-May to late-September 1999 (maximum of 20.4°C). The proposed spawning standard of 12°C for the moving 7-day average of the daily maximum temperatures (September 15 to May 31) was exceeded on 19 days in October 1998 (maximum of 14.6°C), 39 days in late April to mid-May 1999 (maximum of 17.4°C) and 16 days in late September 1999 (maximum of 17.3°C). These data suggest that temperature is a probable factor of decline for salmonids in Little Soos Creek, based on frequent significant exceedances of the existing Class A standard, and proposed rearing and spawning standards (for both maximum and moving 7-day averages) of from 1 to 6°C.

Jenkins Creek

Continuous water temperature data were collected at the King County stream gauge near the mouth of Jenkins Creek (station 26A) from October 1997 to September 1999 (water years 1998 and 1999). The maximum recorded daily temperature during this period was 17.8°C in late July 1998. During the two-year period, the Class A standard of 18°C was never exceeded and the proposed 17.5°C rearing standard was exceeded on two days in late July 1998. The proposed 14.5°C spawning standard (September 15 to May 31) was exceeded on one day in late May 1999 (maximum of 15.1°C) and on three days in late September 1999 (maximum of 14.6°C).

The proposed rearing standard of 15°C for the moving 7-day average of the daily maximum temperatures was exceeded on 55 days from mid-July to mid-September 1998 (maximum of 17°C) and for 40 days from mid-July to late August 1999 (maximum of 15.9°C). The proposed spawning standard of 12°C for the moving 7-day average of the daily maximum temperatures (September 15 to May 31) was exceeded on 13 days in late April to mid-May 1998 (maximum of 13.5°C) and 15 days in late September 1998 (maximum of 14.6°C). In water year 1999, the spawning standard was exceeded on 12 days in mid- to late-May (maximum of 14.1°C) and 15 days in late September (maximum of 14.2°C). These data suggest that temperature is a possible factor of decline for salmonids in Jenkins Creek, based on somewhat frequent exceedances of the proposed rearing and spawning standards (based on moving 7-day averages) of from 1 to 2°C.

Covington Creek

The maximum recorded daily temperature in Covington Creek (station 9A) during water years 1998 and 1999 was 20.2°C in early August 1998. During the two-year period, the Class A standard of 18°C was exceeded on 14 days in July/August 1998 and two days in early September 1999. The proposed 17.5°C rearing standard was exceeded on 17 and four days in 1998 and

1999, respectively. A single measurement (23.2°C) was above the migration threshold of 21°C at station R320 (collected as part of routine monitoring). The proposed 14.5°C spawning standard (September 15 to May 31) was exceeded on two and one days in late May 1998 and May 1999, respectively (maximum of 16.8°C), on 10 days in late September/October 1998 (maximum of 17.3°C) and on 10 days in September 1999 (maximum of 17.6°C).

The proposed rearing standard of 15°C for the moving 7-day average of the daily maximum temperatures was exceeded on 66 days from mid-July to mid-September 1998 (maximum of 18.8°C) and for 17 days from late August to mid-September 1999 (maximum of 16.6°C). The proposed spawning standard of 12°C for the moving 7-day average of the daily maximum temperatures (September 15 to May 31) was exceeded on six days in October 1997 (maximum of 13.7°C), 24 days in May 1998 (maximum of 13.1°C), and 16 days in late September 1998 (maximum of 14.6°C). In water year 1999, the spawning standard was exceeded on 13 days in October 1998 (maximum of 14.8°C), nine days in late May 1999 (maximum of 13.1°C) and 16 days in late September (maximum of 15.7°C). These data suggest that temperature is a probable factor of decline for salmonids in Covington Creek, based on frequent exceedances of the proposed rearing and spawning standards (based on moving 7-day averages) of from 1 to 4°C.

Soosette Creek

Continuous water temperature data were collected at the King County stream gauge near the mouth of Soosette Creek (station 54H) from October 1998 to September 1999 (water year 1999). There were considerable data gaps in water year 1998, so those data are not included in this analysis. The maximum recorded daily temperature during this period was 20.2°C in early August 1999. During the one-year period, the Class A standard of 18°C and the proposed 17.5°C rearing standard were exceeded on 34 and 57 days, respectively, between late May and September. The proposed 14.5°C spawning standard (September 15 to May 31) was exceeded on 20 days from mid-April to late May 1999 (maximum of 18.3°C), and 16 days in late September 1999 (maximum of 17.8°C).

The proposed rearing standard of 15°C for the moving 7-day average of the daily maximum temperatures was exceeded on 132 days from late-May to late-September 1999 (maximum of 19.6°C). The proposed spawning standard of 12°C for the moving 7-day average of the daily maximum temperatures (September 15 to May 31) was exceeded on 19 days in October 1998 (maximum of 13.5°C), 51 days in mid-April to late May 1998 (maximum of 17.1°C) and 16 days in late September 1998 (maximum of 17.8°C). These data suggest that temperature is a probable factor of decline for salmonids in Soosette Creek, based on frequent significant exceedances of the existing Class A standard, and proposed rearing and spawning standards (for both maximum and moving 7-day averages) of from 1 to 6°C.

In summary, temperature is a probable factor of decline for salmonids in the Soos Creek basin for both rearing and spawning in the Soosette, Little Soos and Covington tributaries and the mainstem of Big Soos and a possible factor of decline in Jenkins Creek.

Dissolved Oxygen

Segments of Big Soos, Little Soos and Soosette Creeks are listed on the State’s 303(d) list of impaired water bodies for failing to meet state surface water quality DO standards. The listings are based on numerous excursions measured between 1991 and 1997 at sampling stations L320 (Big Soos RM 10.5), M320 (Big Soos RM 10.0), U320 (Little Soos RM 4.7), X320 (Little Soos RM 3.1), and Y320 (Soosette RM 3.9).

Based on water quality data from 1996 through 1999, the following conclusions can be drawn:

1. **Big Soos Creek**. Fifty-four of 141 DO measurements at stations L320, M320, N320 and Q320 were below Class A and proposed salmonid rearing standard (8.0 mg/L); none of the 76 DO measurements at A320 and P320 were below this standard. In addition, 146 of 217 DO measurements at all sampling locations were below the proposed incubation standard (10.5 mg/L); many of these excursions occurred during the defined salmonid incubation period.

2. **Little Soos Creek**. Twenty of 51 DO measurements were below the Class A and proposed salmonid rearing standard (8.0 mg/L) at sampling station U320; none of the 53 measurements at stations G320 and T320 were below this standard. In addition, 70 of 104 DO measurements were below the proposed salmonid incubation standard (10.5 mg/L) at all sampling locations; many of these excursions occurred during the defined salmonid incubation period.

3. **Jenkins Creek**. All data at sampling station D320 were greater than the Class A and proposed salmonid rearing standard. However, 14 of 39 DO measurements were below the proposed salmonid incubation standard (10.5 mg/L), and many of these occurred during the defined salmonid incubation period.

4. **Covington Creek**. All 127 DO measurements at sampling stations C320, R320 and S320 were greater than the Class A and proposed salmonid rearing standard (8.0 mg/L). However, 44 of 127 DO measurements at all stations were below the proposed salmonid incubation standard (10.5 mg/L); many of these excursions occurred during the defined salmonid incubation period.

5. **Soosette Creek**. Twenty-two of 100 DO measurements at all stations were below than the Class A and proposed salmonid rearing standard (8.0 mg/L). In addition, 44 of 100 DO measurements at all stations were below the proposed salmonid incubation standard (10.5 mg/L); many of these excursions occurred during the defined salmonid incubation period.

In summary, it appears that DO is probably of concern for salmonids in the Soos Creek subbasin. When evaluating individual DO readings, the King County data from 1996 through 1999 exceeded the water quality standards on some occasions, and therefore, support the 303(d) listing.

Turbidity/TSS

None of the Soos Creek subbasin is listed on the State's 303(d) list of impaired water bodies for failing to meet state surface water turbidity standards. Based on the available water quality data from 1996 through 1999, average non-storm turbidity ranged from 0.6 to 4.9 NTUs. The limited storm turbidity data ranged from 0.7 to 5.1 NTUs, except for one measurement at station B320 that was 22 NTUs. When considering all of the data (both non-storm and storm), all but four measurements were less than 20 NTUs; the maximum turbidity measurement was 27 NTUs at sampling station B320.

Average non-storm TSS in the Soos Creek subbasin ranged from 0.66 to 6.06 mg/L, although a few individual measurements were as high as 137 mg/L. Although these were not classified as storm samples, these peak measurements probably occurred shortly after a storm event or some other disturbance that caused a short-term increase in TSS. Storm measurements ranged from <0.5 to 22 mg/L. These data suggest that TSS concentrations in the Soos Creek subbasin occasionally exceed levels that could cause sub-lethal effects if the concentrations were maintained for a long enough duration. However, the duration of the elevated TSS concentrations is unknown and therefore, potential effects cannot be determined. On average, TSS does not appear to be of concern for salmonids, although more data, including concentration and duration, are needed.

pH

None of the Soos Creek subbasin is listed on the State's 303(d) list of impaired water bodies for failing to meet state surface water pH standards. Based on the available data from 1996 through 1999, pH is always between 6.5 and 8.0 at all stations except L320, G320, T320, U320 and X320. At Big Soos (station L320), the two excursions (out of 39 measurements) were 6.1 and 6.4. At the Little Soos Creek sampling stations, one of 39 measurements was 6.3 at G320, two of 16 measurements were 6.4 at T320, and two of 38 measurements were 6.3 at U320. Finally, at Soosette Creek station X320, one of 22 measurements was 6.3. Overall, however, 451 of 459 pH measurements in the Soos Creek subbasin were between 6.5 and 8.0. Therefore, pH is unlikely to be of concern for salmonids, although it may influence the potential toxicity of other chemicals (e.g., metals).

Ammonia

Based on the available water quality data from 1996 through 1999, ammonia is not expected to be of concern for salmonids as none of the data exceed either the acute or chronic water quality standard for ammonia.

Metals

The metals evaluated here (aluminum, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) suggest that they are not of concern for salmonids, with the possible exception of aluminum. Although there are no state water quality standards for aluminum, all three aluminum samples at station A320 exceeded the EPA chronic water quality criterion (87 µg/L). Although the limited data exceed the EPA criterion, it is not likely in a toxic form because the analytical method for determining total recoverable aluminum probably dissolves some aluminum that is not toxic and cannot be converted to a toxic form under natural conditions (U.S. EPA 1988). In addition, these data were collected under storm conditions where elevated suspended solids and organic matter concentrations tends to bind more of the dissolved metal, thereby reducing its bioavailability. However, because data are limited, further evaluations of aluminum should be conducted to confirm whether it is of concern for salmonids.

The same pattern for the basin as a whole is applicable to the Soos Creek data with regard to the detection limits for mercury and selenium (see section 4).

WATER QUALITY TRENDS IN THE SOOS CREEK BASIN

A recent analysis of 20-year trends (1980-99) in King County streams (King County, 2000) examined trends for data collected at four stations (A320, C320, D320, G320) in the Soos Creek Basin (see Figure WQ-2). Time-series plots were used as a preliminary screening tool to examine trends. If a trend was suggested by the time-series plot, the data were then assessed using a Seasonal Kendall's Trend test to test for statistically significant trends. Summary results of the study follow:

1. **Dissolved Oxygen**. During baseline conditions, average DO levels at Soos Creek (A320) were 11.3 mg/L, the highest concentration of any stations in the study. There was no long-term increasing or decreasing trend in DO levels at the four sites.

2. **Temperature**. Temperature has increased at 19 of 23 sites in the study over the 20-year period, including two of four in the Soos Creek basin (based on the Seasonal Kendall's Trend test). It was concluded that most of this increase is probably attributable to urbanization and development, including increased stormwater runoff, and loss of riparian vegetation. This is because there were no temperature trends detected for the same period from two sites on the Middle Green River (stations A319 and B319), both of which are in areas that have experienced little development.

3. **Turbidity/TSS**. Soos Creek (A320) typically exhibited the lowest average turbidity and TSS over the 20-year period for the 23 sites. Baseflow turbidity averaged 1.4 NTU and 2.8 NTU during the dry and wet seasons, respectively. TSS values at Soos Creek averaged 3.4 mg/L. There were no apparent trends for turbidity, but time-series plots suggested that baseflow levels of TSS have been decreasing over time. Only Little Soos Creek (G320), however, showed a statistically significant decreasing trend. Soos Creek (A320) exhibited the highest storm turbidity value (272 NTU) of the nine sampling locations in King County for which stream storm data were available during the 20-year study period (King County 2000).

4. **Ammonia**. Soos Creek also had the lowest average value for ammonia at 0.035 mg/L. Covington Creek (C320) was the only Soos subbasin site to experience a statistically significant increase in ammonia over the study period, but it does not exceed the state standard.

Water quality trend data were not available for other parameters, such as metals.

Turbidity

It is important to note that turbidity data for the Soos Creek basin have been highly variable. As noted above, Soos Creek exhibited the lowest average turbidity (1.4 NTU) during baseflow conditions over the 20-year study period for the 23 sites monitored. Conversely, it also exhibited the highest storm turbidity value (272 NTU) of nine sites monitored during storm conditions during this same period. For the most recent data evaluated in this report (1996-99), the highest turbidity value observed during storm conditions was 27 NTU and average non-storm turbidity ranged from 0.6 to 4.9 NTU.

Contrary to the recent data, however, hatchery staff at the Soos Creek State Fish Hatchery notes that there are problems with excess turbidity in Soos Creek (Kerwin personal communication 2000). The hatchery utilizes a 1/8-acre pond as a settling basin to remove sediment from creek flows prior to its incubation room. Even with the settling basin, there are occasions during the wet season when it is necessary to sweep silt off the eggs up to three times per week. This phenomenon may be explained by either or both of the following scenarios: (1) possible discrepancies between direct observations on a regular basis and data collected during infrequent sampling events, and/or (2) the potential adverse impacts of even moderate turbidity levels during storms on salmonid eggs.

BIOLOGICAL MONITORING IN THE SOOS CREEK BASIN

The Soos Creek basin has been the most extensively monitored for aquatic insects in theGreen/Duwamish watershed. Table WQ-9 shows the B-IBI scores for eight different monitoring stations in the Soos Creek basin between 1995 and 1998. Lower Soosette Creek had the highest index (average = 35) and Little Soos Creek had the lowest index (average = 14). Five of the eight stations were characterized as fair, two of the eight stations were characterized as poor, and one very poor.

Aquatic insect sampling also occurred at one station on Meridian Valley Creek in the Big Soos Creek basin by SalmonWeb (2000) during 1999. The B-IBI score was 14, which is characterized as very poor on the B-IBI index.

TableWQ-9. B-IBI scores for streams in the Soos Creek Basin for 1995 to 1998.

Macroinvertebrate Monitoring Sites	1995 Scores	1997 Scores	1998 Scores
Lower Covington Creek	34	30	N/A
Upper Covington Creek	*	32	N/A
Lower Soos Creek	28	28	N/A
Upper Soos Creek	20	20	N/A
Lower Jenkins	30	28	30
Upper Jenkins	N/A	N/A	22
Lower Soosette Creek	36	N/A	34
Little Soos Creek	14	14	N/A

* Indicates that scores could not be calculated.
N/A = not available.

DATA GAPS

There are probably sufficient data to characterize temperature, dissolved oxygen, pH and ammonia in the Soos Creek subbasin. Available TSS data do not include duration, without which potential effects cannot be accurately evaluated. Furthermore, there are relatively few metals data (between three and 16 occasions), and all were collected under storm conditions. Therefore, additional metals data are needed, especially under baseline (non-storm) conditions.

Other classes of parameters for which no data are available represent significant data gaps. No data were available for pesticides and herbicides, PAHs, or phthalate esters.

MILL (HILL) CREEK

Mill Creek originates from Lake Doloff and Lake Geneva on the plateau west of the Green River Valley. The creek flows from these lakes down Peasley Canyon, a steep ravine that reaches the valley floor near the intersection of SR-18 and SR-167. The Mill Creek basin is approximately 22 square miles in area and also includes Mullen Slough and Midway Creek (see Figure WQ-1). Five jurisdictions are contained in the Mill Creek basin: King County, Federal Way, Algona, Kent, and Auburn. A comprehensive Mill Creek Water Quality Management Plan was completed by King County in 1993 (King County 1993).

Most of the upland plateau area in the west of the basin is residential. Much of the valley floor to the east is a mixture of commercial and industrial structures, agriculture, idle pasture, and open space with scattered homes. The southeastern and southern areas are heavily urbanized.

Mill Creek is classified as a Class A surface water (WAC-173-201A-120). According to the Green/Duwamish Nonpoint Action Plan (King County 1989), the Mill Creek, Mullen Slough, and Midway Creek drainages are “the most polluted streams draining into the Green/Duwamish system.” Metro (1991) identifies Mill Creek as one of two streams in its survey having the poorest water quality, with chronically low dissolved oxygen (DO) levels and high temperatures, bacterial counts, nutrients and turbidity.

Three reaches along Mill Creek are listed on the state’s 303(d) list of impaired water bodies for failing to meet state surface water standards. The reach near the mouth of Mill Creek is listed for fecal coliforms and DO. Further upstream on Mill Creek, these same two parameters and temperature are listed. Lastly, the reach of Mill Creek just upstream of Peasley Canyon is listed for fecal coliforms. The reach of Mullen Slough near its mouth at the Green River is also listed for fecal coliforms, temperature, and DO.

According to the Mill Creek Water Quality Management Plan (King County 1993), the most significant water quality problems in Mill Creek are:

- A severe depression or sag in DO levels between approximately river mile (RM) 5.6 and RM 3.3 in Auburn (see Figure WQ-6). Dissolved oxygen levels in this reach are regularly below the standard of 8 mg/L and often as low as 3 mg/L. There are also extremely low DO levels in the Algona tributary that enters Mill Creek at the SR-18 and SR-167 intersection.

- High summer water temperatures in the Algona tributary and in Mill Creek from the outlet of Peasley Canyon to the mouth. Average daily maximum temperatures from July 20 to September 10, 1991 were nearly 20^{o}C in Mill Creek.

- Erosion of stream banks in Peasley Canyon, causing high suspended solids and turbidity downstream.

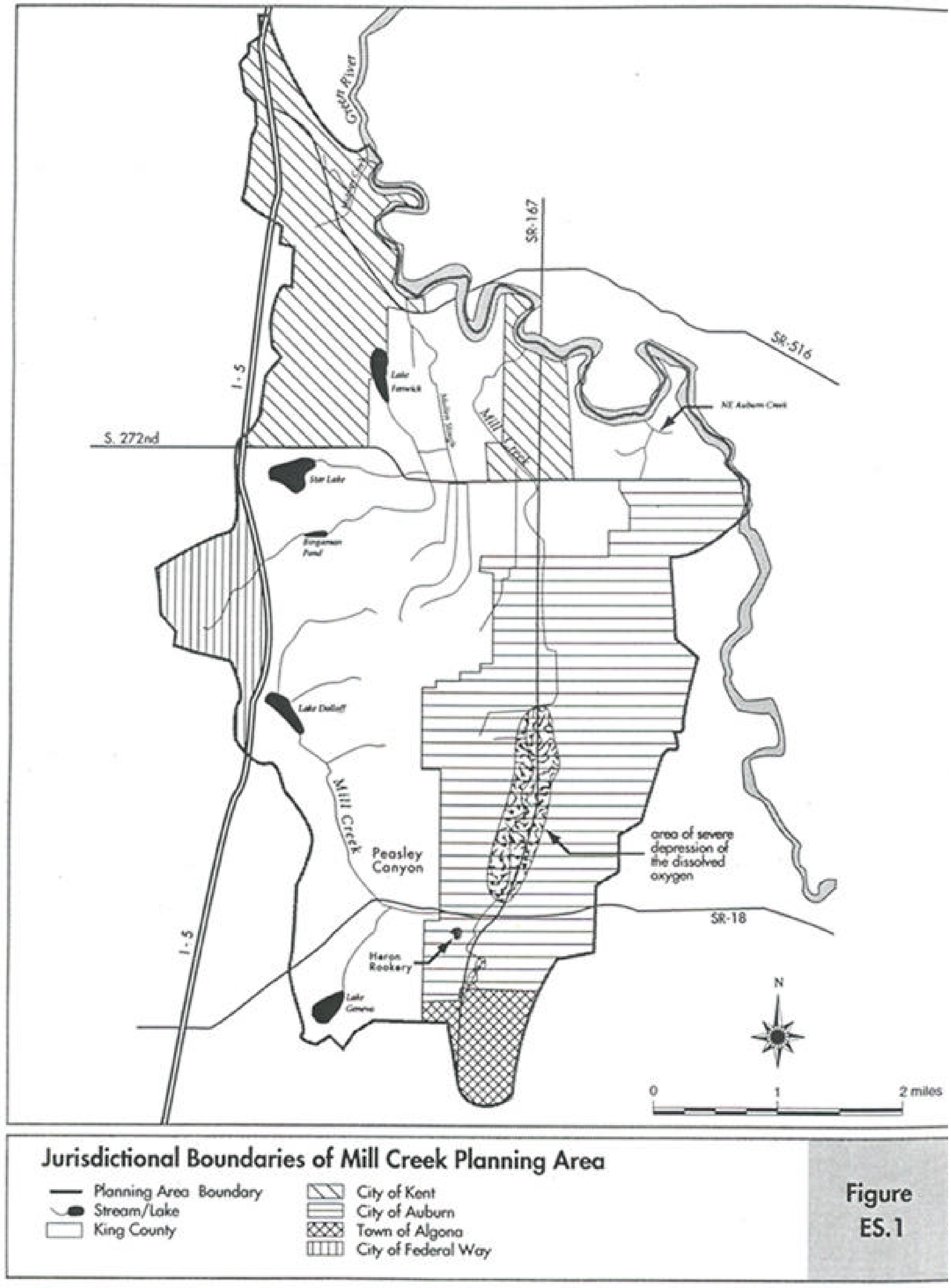


Figure WQ-6. Location of Dissolved Oxygen Sag on Mill Creek (Mill Creek Water Quality Management Plan, King County 1993).

MULLEN SLOUGH

The Mullen Slough watershed, within the Mill Creek Basin, covers approximately 3,400 acres in area. Three small streams flowing from the uplands along the west side of the basin originate in Lakes Star and Fenwick and Bingaman Pond. Land use in the valley floor is essentially agriculture, wetlands, or idle lands, and residential or undeveloped forest in the uplands. Baseflow and storm events were sampled by King County between February 1990 and February 1991. The most significant water quality problems in Mullen Slough identified by King County (1993) are similar to Mill Creek, including low DO levels, high summer water temperatures, and high ammonia-nitrogen concentrations.

- DO levels in flows coming from the uplands, entering Mullen Slough from the west, typically range between 8 and 12 mg/L. However, downstream in Mullen Slough, near the confluence with the Green River, DO is typically below 6 mg/L and frequently as low as 2 mg/L. Low values have been measured even during the winter months.

- Temperatures in Mullen Slough regularly exceed state standards during the summer months. From July 20 to September 10, 1991, maximum daily temperatures averaged 22^{o}C during low flow conditions.

- Ammonia-nitrogen concentrations in lower Mullen Slough during the sampling period (King County 1993) were measured between 4 and 8 mg/L, considerably higher than the chronic standard of about 1.8 mg/L. Because the upland station did not exhibit such elevated levels, poor manure handling practices in the valley floor appear to be the primary source of elevated ammonia levels.

MIDWAY CREEK BASIN

The Midway Creek basin encompasses about 750 acres in the northern portion of the Mill Creek basin. The upland area is mostly developed. South of SR-516 is mostly developed in residential uses with discharges to a steep ravine in the south fork of Midway Creek. The watershed has approximately four miles of heavily used roads (Interstate-5, SR-516 and Military Rd.). The Kent-Highlands landfill site (90 acres) is also within this watershed; however, the stormwater that directly enters Midway Creek does not appear to come from refuse areas.

Analysis of data from 1986 to 1989 from Station 8 in Kent (near the mouth of Midway Creek) (Kent 1991) indicates that the water quality is generally good, with the exception of fecal coliforms (King County 1993). Temperature, DO and metals typically met standards, although the DO concentrations were usually less than 100 percent saturation (King County 1993).

WATER QUALITY—EXISTING CONDITIONS

Only one station in the Mill Creek subbasin was included in the King County Streams program between 1996 and 1999. The station (A315) is located near the mouth of Mill Creek just west of the West Valley Highway (Hwy 167) (Figure WQ-2). The surrounding area contains several major roadways, pastureland and low-density residential development.

At station A315, six parameters (temperature, DO, pH, turbidity, TSS and ammonia) were analyzed in 36 to 38 samples during nonstorm conditions between 1996 and 1999. These same parameters were measured during storm conditions on 14 occasions. Additionally, total and dissolved metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) were analyzed at station A315 during storm conditions on roughly 13 and 7 occasions, respectively. Total and dissolved aluminum was analyzed on three and one occasions, respectively, during storm conditions. Comparisons of data to standards or criteria are detailed below.

Temperature

Continuous water temperature data were collected at the King County stream gauge near the mouth of Mill Creek (station 41A) from October 1999 to September 2000 (water year 2000). The maximum recorded daily temperature during this period was 23.8°C in late June 2000, which exceeds the migration blockage threshold (21°C). The Class A standard of 18°C and the proposed 17.5°C rearing standard were exceeded on 69 and 77 days, respectively, between May and September 2000. The proposed 14.5°C spawning standard (September 15 to May 31) was exceeded on 33 days in April and May of 2000 (maximum of 19.3°C).

The proposed rearing standard of 15°C for the moving 7-day average of the daily maximum temperatures was exceeded on 121 days during water year 2000 from early May to mid-September. It was continuously over 15°C from mid-May to mid-September. The maximum 7-day average was 22.5°C in early August. The proposed spawning standard of 12°C for the moving 7-day average of the daily maximum temperatures (September 15 to May 31) was exceeded continuously from April 3 to May 31, 2000 (maximum of 17.7°C in late May). No data were available for late September 2000. These data indicate that temperature is a probable factor of decline for salmonids in Mill Creek, based on frequent large exceedances of the Class A standard and proposed rearing and spawning standards of 4 to 6°C.

Dissolved Oxygen

Numerous DO concentrations (minimum of 2.5 and 4.8 mg/L for non-storm and storm conditions, respectively) were below the Class A and proposed salmonid rearing water standard (8.0 mg/L). In addition, DO concentrations were always below the proposed salmonid incubation standard (10.5 mg/L) at station A315 between 1996 and 1999 during the defined incubation period (see Figure WQ-7). Chinook are not known to spawn in this reach of Mill Creek, however, coho, chum, and winter steelhead adults have been observed spawning in Mill Creek (WDFW Spawning Ground Survey database, Malcom pers comm, see FOD subbasin chapter). Thus, the incubation standard would be applicable to this location, indicating that this reach is a known problem area for salmonids. This reach had the lowest DO concentrations during the 1996-99 study period. Based on DO levels falling below both the incubation and rearing standard for this reach, DO in this area is a probable factor of decline for salmonids.

Turbidity/TSS

Average turbidity is 8 and 13 NTUs for non-storm and storm conditions, respectively, with a peak storm turbidity measurement of 34 NTUs. TSS concentrations averaged 6 and 18 mg/L for storm and non-storm conditions, respectively, with a peak storm measurement of 54 mg/L.

During storm events, TSS concentrations occasionally exceeded levels that could cause sub-lethal effects if the concentrations were maintained for a long enough duration. However, the duration of the elevated TSS concentrations is unknown, and therefore, the potential effects cannot be determined.

pH

Nearly all measurements were between 6.5 and 7.6. Only four of 52 measurements were below the Class A standard of 6.5, with a minimum measurement of 6.3. Therefore pH in Mill Creek in the vicinity of A315 is unlikely to be of concern for salmonids, although it may influence the potential toxicity of other chemicals (e.g., metals).

Ammonia

The ammonia data collected from 1996 to 1999 were below both the acute and chronic state water quality standards for ammonia. Therefore, ammonia is not expected to be of concern for salmonids at station A315. However, it should be noted that historic data indicated a problem with ammonia levels exceeding the chronic standard along Mullen Slough.

Metals

The metals evaluated at station A315 (aluminum, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) are not of concern for salmonids, with the possible exception of aluminum. Although there are no state water quality standards for aluminum, each of the three aluminum samples (collected during storm conditions) exceeded the EPA chronic water quality criterion (87 µg/L). Two of the three samples (1,410 and 1,610 µg/L), exceeded the EPA *acute* water quality criterion (750 µg/L). Although the limited data exceed the EPA criterion, it is not likely in a toxic form because the analytical method for determining total recoverable aluminum probably dissolves some aluminum that is not toxic and cannot be converted to a toxic form under natural conditions (U.S. EPA 1988). In addition, these data were collected under storm conditions where elevated suspended solids and organic matter concentrations tends to bind more of the dissolved metal, thereby reducing its bioavailability. However, because data are limited, further evaluations of aluminum should be conducted to confirm whether it is of concern for salmonids.

The same pattern for the basin as a whole is applicable to the Mill Creek data with regards to the detection limits for mercury and selenium (see section 4).

DATA GAPS

There are probably sufficient data to characterize temperature, DO, pH and ammonia at station A315; however, no data were available for any other location on Mill Creek. Therefore, the spatial variability of these parameters in Mill Creek is a data gap, since station A315 is likely not representative of the entire subbasin. For instance, historic data on Mullen Slough showed exceedances of the chronic ammonia standard, even though they did not occur on Mill Creek. Available TSS data do not include information on duration, therefore, potential effects cannot be accurately evaluated. Furthermore, there are relatively few metals data (between one and 13 occasions), and all were collected under storm conditions. Therefore, additional metals data are needed, especially under baseline (non-storm) conditions.

Other classes of parameters for which no data were available represent significant data gaps. No data were available for pesticides and herbicides, PAHs, or phthalate esters.

BLACK RIVER BASIN (SPRINGBROOK CREEK)

The Black River has undergone major changes over the past century. Significant drainage modifications have substantially reduced the size of the Black River basin to a 24-square mile area on the east side of the Green River south of Renton. Springbrook Creek, originating in the south of the basin in Kent, is the primary stream draining this basin. The Black River Basin Water Quality Management Plan (City of Renton 1993), developed by the City of Renton, contains the most detailed information on water quality for this basin. Water quality data (Kent 1991) and fisheries assessment information (Kent 1995) has also been collected by the City of Kent in the lower portion of the basin. One station at the mouth of Springbrook Creek (0137) is regularly monitored for water quality by the King County streams program.

The entire Black River basin is developed in urban land uses, lying west of the urban growth boundary. Approximately 27 percent of the basin lies in Renton, 65 percent in Kent, less than 2 percent in Tukwila, and the remainder in unincorporated King County. Land uses within the basin are primarily residential, commercial, and industrial with several major freeways (Interstate 405, Highway 167). There is also a Superfund site at Western Processing in Kent.

Springbrook Creek is on the 303(d) list for DO, temperature, fecal coliforms, and a variety of metals (chromium, cadmium, copper, mercury, and zinc). A segment of Mill Creek (Kent), which drains into Springbrook Creek, is also on the 303 (d) list for metals (cadmium, copper, zinc) and sediment (based on a sediment bioassay).

WATER QUALITY—HISTORICAL CONDITIONS

Water quality and flow data have been collected at station 0317 since 1977 by King County (Metro). The Department of Ecology collected water quality data near the mouth of Mill Creek (station 09E070) from 1984 to 1990. Chronic water quality problems in the basin include exceptionally low concentrations of DO, high turbidity, high levels of fecal coliform bacteria, TSS, and ammonia.

Springbrook Creek DO has been as low as 2.1 mg/L with a mean of 6.4 mg/L between 1986-1991 (based on the Metro data). During this same period, mean turbidity was 26 NTU (range: 2.2 to 170) and mean suspended solids was 61 mg/L (range: 5.1 to 2,384). The mean for copper was 9.8 µg/L (range: <2 to 29) in comparison to the chronic criterion of 7 µg/L (for a hardness of 50 mg/L).

Water quality was monitored for the Black River Basin Plan from September 1991 to April 1992 (City of Renton 1993). Two stations were located on Springbrook Creek and one on the Black River. These study results were similar to the previous data, including elevated temperatures and low DO levels (although it is important to note that no summer sampling was included in this study). There were also high levels of metals, fecal coliform bacteria, nutrients and turbidity during storm flows.

Stream sediment loading within the basin is contributed from two primary sources: soil erosion and stream channel erosion (City of Renton 1993). Soil erosion is caused primarily by land clearing activities associated with construction and development. Stream channel erosion is common in the steeper gradient portions of Panther Creek and Springbrook Springs tributary where excess runoff from development has accelerated natural erosion processes. Sediment deposits in the lower section of Springbrook Springs have reached depths of five feet (King County 1987).

The Black River Basin plan (City of Renton 1993) notes that under present conditions, the lack of suitable spawning habitat and questionable rearing capacity due to degraded water quality, especially during warm summer months, result in both Springbrook Creek and Panther Creek offering little in the way of fish habitat. It further states that the presence of heavy metals represents a potentially adverse factor for the aquatic resources of the basin.

The City of Kent Water Quality Program report (Kent 1991) summarizes results of sampling from 1986 to 1989 at six stations in the basin for eight parameters (temperature, DO, turbidity, ammonia, nitrate, fecal coliform, zinc, and total phosphorus). The report noted that water quality at most sampling stations was poor, with particularly degraded conditions at station 1 (Springbrook Creek just downstream of the confluence with Mill Creek) and station 5 (lower Mill Creek). Standards were routinely exceeded for DO, zinc, fecal coliforms, and turbidity.

WATER QUALITY—EXISTING CONDITIONS

King County collected data from one location near the mouth of Springbrook Creek (sampling station 0317) for the Stream Monitoring Program between 1996 and 1999 (Figure WQ-1). At station 0317, six parameters (temperature, DO, pH, turbidity, TSS and ammonia) were analyzed in 37 samples during nonstorm conditions between 1996 and 1999. These same parameters were measured during storm conditions on 13 occasions. Additionally, total and dissolved metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) were analyzed at station 0317 during storm conditions on roughly 12 and 6 occasions, respectively. Total aluminum was analyzed on three occasions during storm conditions. Comparisons of data to standards or criteria are detailed below.

Temperature

The 303(d) temperature listing for Springbrook Creek is based on excursions measured at Ecology sampling stations 09E070 (RM 0.1) and 09E090 (RM 1.5) on Mill Creek between 1988 and 1996. No continuous temperature data were available for Springbrook Creek. Based on the water quality data from station 0317 from 1996 through 1999, only one exceedance of the Class A standard (18°C) was measured. However, 14 of 37 measurements exceeded the proposed salmonid spawning standard (14.5°C), two of which occurred during the salmonid spawning season. In addition, two of the 37 measurements exceeded the proposed salmonid rearing standard (17.5°C). No temperature measurements exceeded the salmonid migration threshold (21°C). Together, these data suggest that temperature is a possible factor of decline for salmonids in Springbrook Creek.

Dissolved Oxygen

The 303(d) DO listing for Springbrook Creek is based on multiple excursions measured at the same Ecology sampling stations that exceeded temperature standards. Based on the water quality data from station 0317 from 1996 though 1999, only nine of 38 measurements met the Class A and proposed salmonid rearing standard (8.0 mg/L), and only two of those met the proposed salmonid incubation standard (10.5 mg/L). Therefore, DO is of concern for salmonids.

Turbidity/TSS

Based on the available water quality data from 1996 through 1999, average turbidity was 15 NTUs for both non-storm and storm data, with maximum values of 30 and 22 NTUs, respectively. Only eight of 37 non-storm measurements and two of 12 storm measurements were greater than 20 NTUs; however, no samples were less than 6.4 NTUs.

Average TSS was 9.1 and 29.7 mg/L for non-storm and storm measurements, respectively. The maximum non-storm TSS measurement was 36.8 mg/L; the other 36 non-storm measurements were between 3.2 and 20.6 mg/L. The maximum storm TSS measurement was 75.3 mg/L, suggesting that TSS concentrations occasionally exceed levels that could cause sub-lethal effects if the concentrations were maintained for a long enough duration. However, the duration of the elevated TSS concentrations is unknown, and therefore, potential effects cannot be determined. More data, including concentration and duration, are needed.

pH

Based on the water quality data from 1996 through 1999, 35 of 37 non-storm measurements were between 6.5 and 7.4; two measurements were below at 6.3 and 6.4. Three of 13 storm measurements were below 6.5, with a minimum of 6.1. All other storm measurements were between 6.8 and 7.3. Therefore, overall pH is unlikely to be of concern for salmonids, although it may influence the toxicity of other chemicals (e.g., metals).

Ammonia

Based on the available water quality data from 1996 though 1999, ammonia is not expected to be of concern for salmonids as none of the data exceed either the acute or chronic water quality standard for ammonia.

Metals

The 303(d) listings for cadmium, copper, chromium, mercury and zinc are based on excursions beyond state standards measured between 1984 and 1990 at Ecology sampling stations 09E070 (Mill RM 0.1) and 09E090 (Mill RM 1.5), King County sampling station 0317 (Springbrook RM 1.0), and at stations described in Yake (1985). Metals evaluated in this report (aluminum, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc) using the 1996 though 1999 data suggest that metals are not of concern for salmonids, with the possible exception of aluminum. Although there are no state water quality standards for aluminum, all three aluminum samples at station 0317 exceeded the EPA chronic water quality criterion (87 µg/L). Two of the three samples exceeded the EPA *acute* criterion (750 µg/L). Although the limited data exceed the EPA criterion, it is not likely in a toxic form because the analytical method for determining total recoverable aluminum probably dissolves some aluminum that is not toxic and cannot be converted to a toxic form under natural conditions (U.S. EPA 1988). In addition, these data were collected under storm conditions where elevated suspended solids and organic matter concentrations tends to bind more of the dissolved metal, thereby reducing its bioavailability. However, because data are limited, further evaluations of aluminum should be conducted to confirm whether it is of concern for salmonids.

The same pattern for the basin as a whole is applicable to the Springbrook Creek data with regards to the detection limits for mercury and selenium (see section 4.).

BIOLOGICAL MONITORING IN MILL CREEK (KENT)

Aquatic insect sampling occurred at one station on Mill Creek (Kent) in the Black River Basin at Earthworks Park in Kent during 1999 (SalmonWeb 2000). The B-IBI score was 10, which is characterized as very poor on the B-IBI index. This was the lowest score recorded in the Green/Duwamish watershed from the biological monitoring effort.

DATA GAPS

There are probably sufficient data to characterize temperature, DO, pH and ammonia in Springbook Creek. The lack of continuous temperature data is a data gap because data do not necessarily reflect daily maximum temperatures and the duration of temperature exceedances. Similarly, available TSS data do not include duration, without which potential effects cannot be accurately evaluated. Furthermore, although there appears to be adequate metals data collected during storm events at station 0317, no baseline (non-storm) data were available. Therefore, additional data are needed, especially for aluminum. There are no recent metals data available for other stations in the Black River Basin.

Other classes of parameters for which no data were available represent significant data gaps. No data were available for pesticides and herbicides, PAHs, or phthalate esters.

LIST OF TABLES

Table WQ-E1. Projected water quality factors of decline based on data evaluated in this report.

Table WQ-E2. Detailed water temperature and dissolved oxygen projected factors of decline.

Table WQ-1. Water quality beneficial uses for surface waters of the State of Washington.

Table WQ-2. Water quality standards for freshwater based on beneficial use classification.

Table WQ-3. State water quality standards for metals and pentachlorophenol (µg/L).

Table WQ-4. Summary of water bodies and parameters on 1998 303(d) list for water.

Table WQ-5. B-IBI scores for Middle Green River stations in 1999 (Salmon Web 2000).

Table WQ-6. Site abbreviations from the Duwamish River WQA.

Table WQ-7. Number of non-storm and storm samples collected in the Duwamish.

Table WQ-8. Summary of number of samples analyzed from October 1996 to December 1999 for each parameter in the Newaukum Creek basin.

Table WQ-9. B-IBI scores for streams in the Soos Creek basin for 1995 to 1998.

LIST OF FIGURES

Figure WQ-1. Sampling locations in the Duwamish and Lower Green River and tributaries.

Figure WQ-2. Sampling location in the Lower and Middle Green River and tributaries.

Figure WQ-3. Sampling locations in the Upper Green River.

Figure WQ-4. Water bodies and parameters on 303(d) list for water.

Figure WQ-5. Annual Recorded Maximum Temperature in the Duwamish River, 1970-1998 (Pentec 1999)

Figure WQ-6. Location of Dissolved Oxygen Sag on Mill Creek (Mill Creek Water Quality Management Plan, King County 1993)

Figure WQ-7. Hill/Mill Creek (A315) dissolved oxygen concentrations compared to current and proposed DO standards.

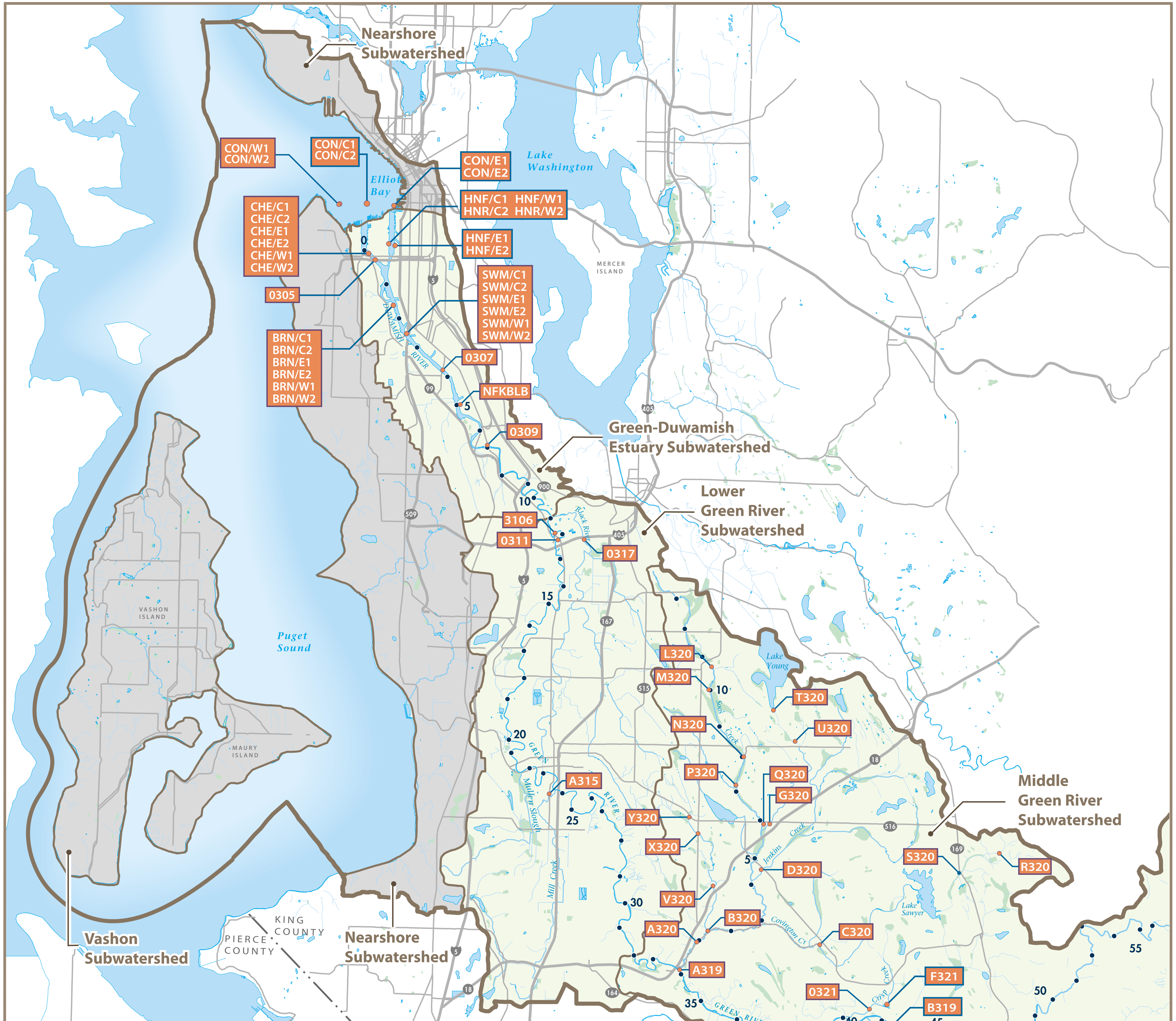


Figure WQ-1

Water Quality Sampling Locations

Duwamish and Lower Green River and Tributaries

- • 10 River Mile & Number
- A319 Water Quality Sampling Site & Number
- Major Road
- River/Stream
- King County Boundary
- Subwatershed Boundary
- Open Water
- Wetlands
- King County WRIA 9 Area
- Area not evaluated (Nearshore and Vashon Subwatersheds were not evaluated in this analysis).

N

0 2 4 Miles

October 2000

King County Department of Natural Resources

File Name: 0012 W9 WQ-1.eps LP

Produced by: GIS & Visual Communications Unit, WLR King County Dept. of Natural Resources

Figure WQ-2

Water Quality Sampling Locations

Lower and Middle Green River and Tributaries

- 10 River Mile & Number
- A319 Water Quality Sampling Site & Number
- Major Road
- River/Stream
- King County Boundary
- Subwatershed Boundary
- Open Water
- Wetlands
- King County WRIA 9 Area

N

0 2 4 Miles

August 2000

Sources:
1997 KC/DOE Hydrography Project,
1990 KC Wetlands Inventory,
KC Standard WRIA & Subbasin Boundaries.

File Name:
0012 W9 WQ-2.eps lp

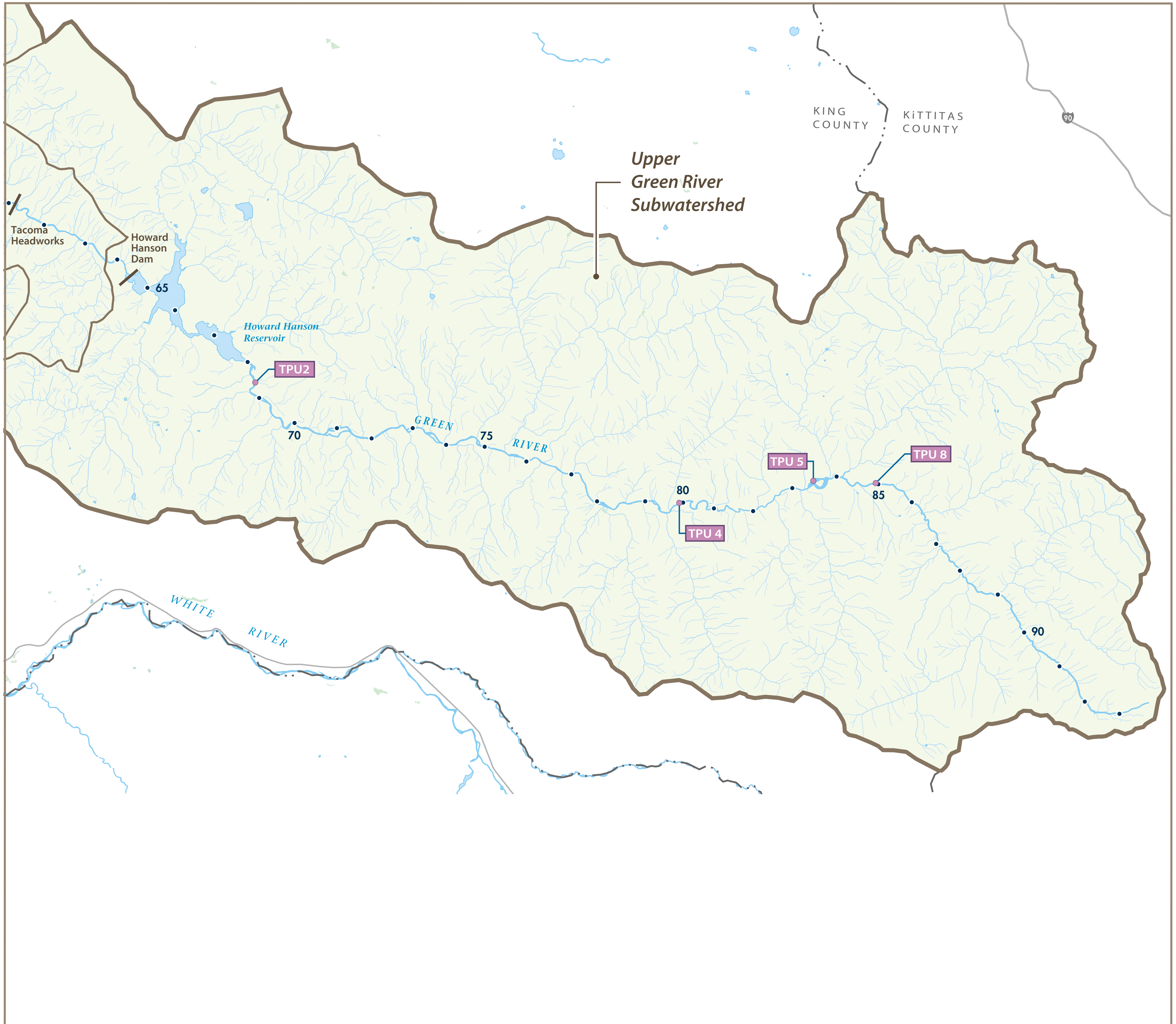
Produced by:
GIS & Visual Communications Unit, WLR
King County Dept. of Natural Resources

King County
Department of Natural Resources

Figure WQ-3

Water Quality Sampling Locations

Upper Green River



- 10 River Mile & Number
- TPU2 Tacoma Public Utility Water Quality Sampling Site & Number
- Major Road
- River/Stream
- King County Boundary
- Subwatershed Boundary
- Open Water
- Wetlands
- King County WRIA 9 Area

N

0 2 4 Miles

August 2000

File Name:
0012 W9 WQ-3.eps

Produced by:
GIS Visual Communications Unit, WLR
King County Dept. of Natural Resources

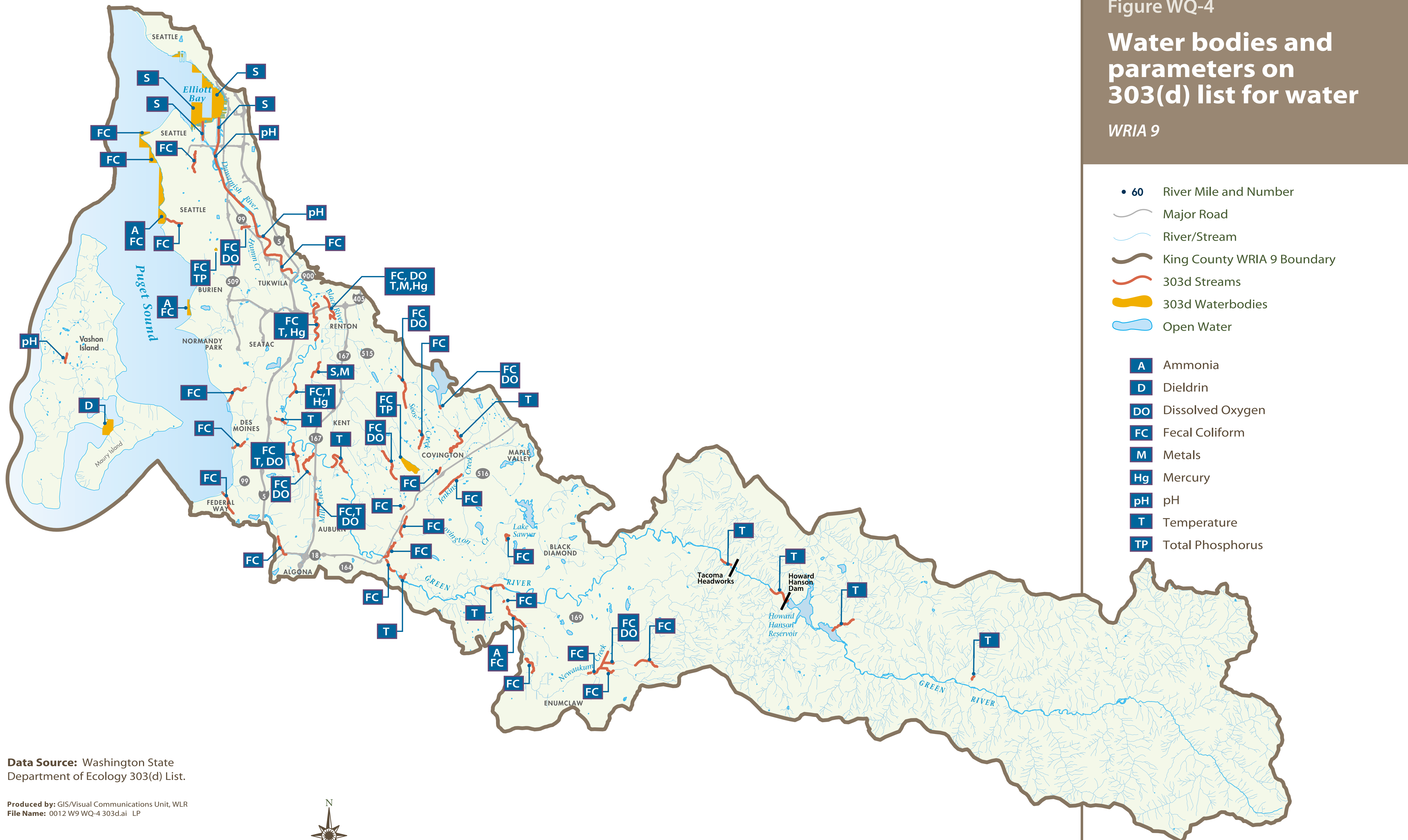
Sources:
1997 KC/DOE Hydrography Project,
1990 KC Wetlands Inventory,
KC Standard WRIA & Subbasin Boundaries.

King County
Department of Natural Resources

Figure WQ-4

Water bodies and parameters on 303(d) list for water

WRIA 9



Data Source: Washington State Department of Ecology 303(d) List.

Produced by: GIS/Visual Communications Unit, WLR
File Name: 0012 W9 WQ-4 303d.ai LP

King County
Department of Natural Resources

April 2000

Figure WQ-5. Annual Recorded Maximum Temperature in the Duwamish River, 1970-1998 (Pentec, 1999).

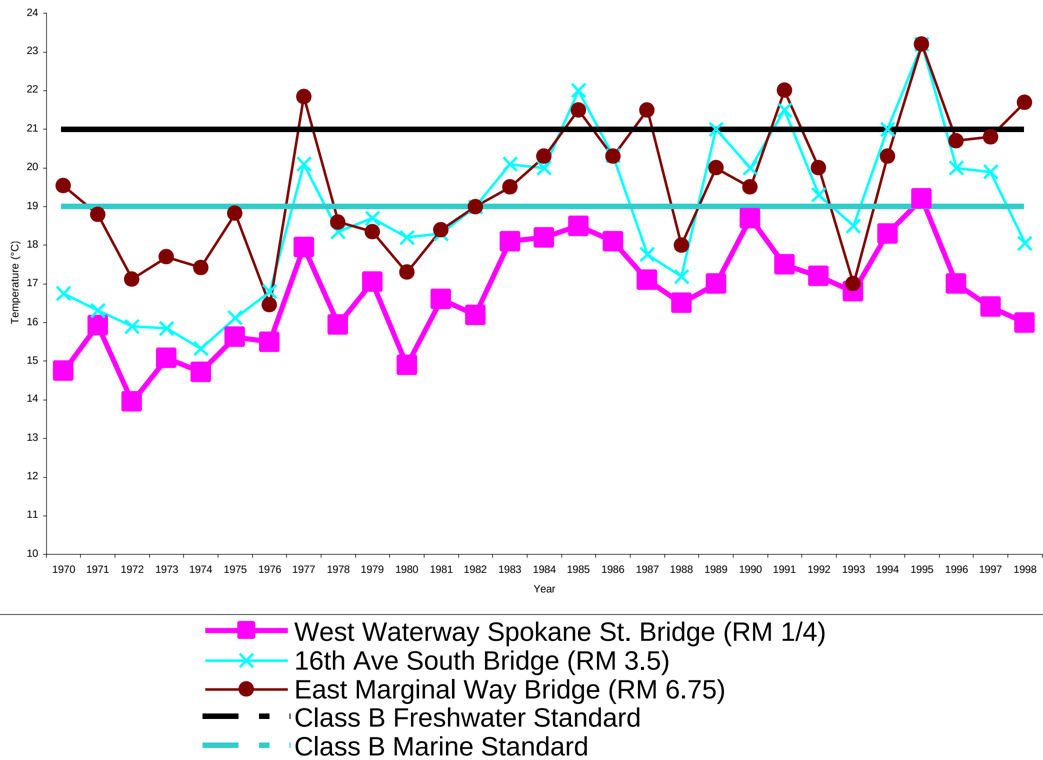
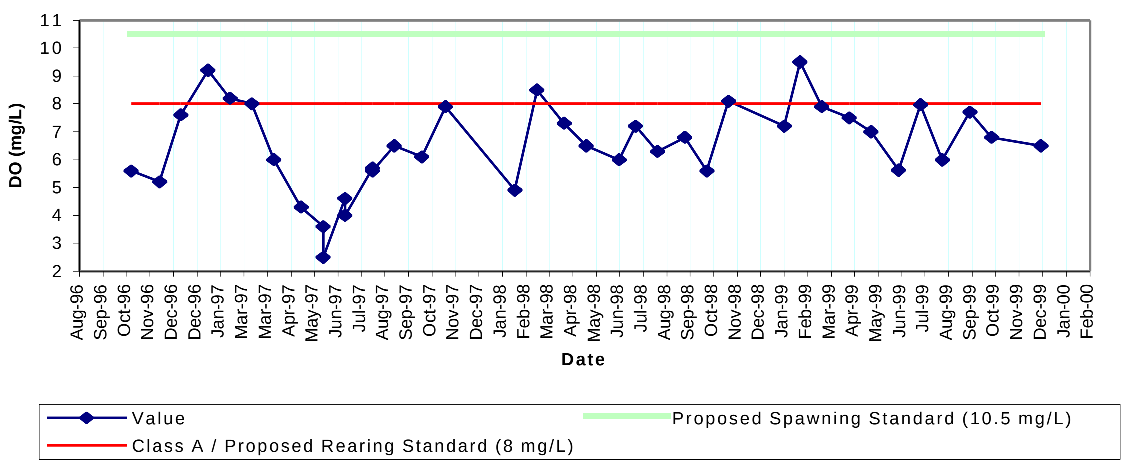


Figure WQ-7. Hill/Mill Creek (A315) Dissolved Oxygen Concentrations Compared to Current and Proposed DO Standards



PART II: FACTORS OF DECLINE/CONDITIONS

2. Mainstem Green/ Duwamish River Conditions

2.1. Hydrology

2.2 Sediment Transport

2.3 Hydromodification

2.4 Riparian Condition

2.5 Fish Passage

2.6 Non-Native Species

2. MAINSTEM GREEN/DUWAMISH RIVER HABITAT CONDITIONS

SALMONID HABITATS IN THE MAINSTEM GREEN/DUWAMISH RIVER BASIN, WRIA 9

GENERAL OVERVIEW

The mainstem Green/Duwamish River is perhaps the most hydrologically and habitat altered large river system in the Puget Sound ecosystem. Changes in the landscape began when early Euro-American settlers started settling the lower basin sometime around 1850. These early settlers began altering the habitats of the lower river valley in the vicinity of what is now Kent and Tukwilla. Bank hardening projects probably started with the first railroad bridges in 1867, levee construction was initiated before 1875, the White River was diverted into the Puyallup River basin in 1906, the Black River diverted into Lake Washington in 1916, the City of Tacoma water diversion dam was finished in 1913, Howard Hanson Dam completed in 1962 and most of the Duwamish estuary had been filled by 1940. Currently, approximately 97 percent of the historic estuary has been filled or deepened, 70 percent of the historic watershed has been diverted out of the basin, and over 90 percent of the historic floodplain is no longer connected due to the construction of flood protection structures (including Howard Hanson Dam).

The Green/Duwamish River has its origins in the Cascade Mountains at an approximate elevation of 4500 feet south in the vicinity of Blowout Mountain and Snowshoe Butte. The river flows for over 93 miles in a northwesterly direction and enters the Puget Sound estuary via Elliot Bay. In this chapter, the mainstem Green/Duwamish River is subdivided into the habitat parameters that effect the survival of salmonids as follows:

- Hydrology (Chapter 2.1);
- Sediment Transport (Chapter 2.2);
- Hydromodification (Chapter 2.3);
- Riparian (Chapter 2.4);
- Fish Passage (Chapter 2.5); and
- Non-Natives (Chapter 2.6).

Each habitat parameter has been further broken into river reaches that have been determined by anthropogenic features. These river reaches are described by river miles in the manner of Williams (1975) and are:

- Green/Duwamish River estuary – RM 0.0 to 11.0;
- Lower Green River subwatershed - RM 11.0 to 32.0;
- Middle Green River subwatershed - RM 32.0 to 64.5; and
- Upper Green River subwatershed - RM 64.5 to RM 93 (headwaters).

Additionally, in the appropriate habitat parameters, we have included information on two tributary streams (Soos Creek and Newaukum Creek) that are particularly important to chinook salmon.

2.1 HYDROLOGY

2.1 HYDROLOGY

EXECUTIVE SUMMARY

LITERATURE REVIEW

Several historic events and landuse trends have combined to have a profound effect on the hydrology of the Green River. These include four large engineering projects:

- Diversion of the White River in 1906;
- Diversion of the Cedar/Black River in 1913;
- Construction of Tacoma Water's Headworks Diversion Dam in 1911; and
- Construction of Howard Hanson Dam (HHD) in 1962.

In addition, construction of flood control levees as well as substantial agricultural development and urbanization in the lower basin have also influenced altered the hydrology of the Green River.

The flow regime of the lower Green River was first profoundly changed in the early 1900's by the permanent diversion of the White River into the Puyallup River for flood control purposes. Soon thereafter (in 1916), the Cedar/Black River was diverted into Lake Washington to facilitate navigation through the Ship Canal. The White and Cedar/Black Rivers combined previously comprised approximately 60 percent of the watershed in total acreage, and contributed a commensurate amount of flow to the lower Green/Duwamish River. Diversion of the White River in particular radically reduced summer low flows and altered the lower Green River's sediment supply (Dunne and Dietrich 1978). The White River, being glacially fed, tends to have higher summer flows, and carries a greater sediment load (per unit drainage area) than the lower gradient, non-glacial Green River. Recent groundwater investigations indicate that the White River is still connected to the Green River via subsurface flows, providing approximately 56 cfs to the lower river in the late summer (Pacific Groundwater Group 1999).

In 1911, the City of Tacoma constructed a diversion dam at RM 61 on the mainstem Green River to capture water for municipal and industrial water supply. The dam and diversion were completed in 1913. Since that time, Tacoma has been almost continuously diverting up to 113 cfs from the mainstem Green River to meet the needs of the rapidly expanding population in Puget Sound. This diversion constitutes approximately 12 percent of the average annual flow at Palmer, the point of diversion. A portion of this water may be replaced during periods of high turbidity by water drawn from a well field that taps the North Fork Green River aquifer.

In 1961, construction of HHD again substantially changes the hydrologic regime of the Green River. Floods greater than approximately 12,000 as recorded at the USGS at Auburn cfs (formerly a two-year return interval event) have been prevented, while the duration of moderate flows (3,000 to 5,000 cfs) has increased due to metered release of floodwaters stored behind the dam. Howard Hanson Dam is also authorized to store water during the summer to augment late summer low flows. Seasonal storage has inundated about 7.5 miles of former riverine habitat in the Upper Green River sub-watershed. Filling of the conservation pool to target levels during the late spring temporarily reduces flows and has historically intercepted freshets that were important mechanism for initiating and expediting the downstream migration of juvenile salmonids.

More recently, urban development in the lower basin has resulted in substantial increases in stormwater runoff from small tributary streams. This in turn has contributed to larger and more frequent peak flows during the winter, and reduced recharge of shallow aquifers that formerly sustained flows during the late summer and fall. Similar effects, though not as severe, occur in the middle and upper watersheds as a result of land clearing for residential development, agriculture and forestry. The overall effect of development on flows in the lower mainstem Green River is difficult to discern due to the overwhelming changes in flow resulting from the diversions, channelization, and HHD.

"NATURAL FLOW ANALYSIS"—HYDROLOGY ADDENDUM

In order to better understand the effects of these two significant public works projects on downstream hydrology, a trial analysis of hydrologic change in the Green River was conducted. This analysis is included as an addendum to this chapter. The primary goals of this analysis were twofold: 1) to determine whether such an analysis is practical and feasible for assessing hydrologic impacts on Green River ecology; and 2) to identify clear areas of hydrologic alteration and their potential ecological implications.

The evaluation focused on the middle Green River between Palmer and Auburn, and addressed only the effects of the operations of HHD and the City of Tacoma's flow diversion. No attempt was made to evaluate "historic" conditions prior to the White and Cedar Rivers being diverted from the watershed, or prior to logging practices commencing above HHD.

The technique utilized considers all major aspects of the flow regime having the potential to affect ecological processes and habitat conditions in the study reach. Given the relatively new nature of this type of analysis, results are preliminary and the methodology should be viewed as a tool that can be modified to improve its relevance to evaluation of Green River ecology.

The Range of Variability approach developed by Richter et. al. (1996, 1997) was modified for application to the Green River. The period of record used was 1964-1995. Flows for the "with-projects" condition were based on the measured data from the USGS gage site at Palmer. The natural or "without-projects" flows are based on a simulation using the Howard Hanson Reservoir inflow data adjusted for reservoir storage and routing. The two data sets are consistent in terms of underlying climate and land use conditions.

Several trends are evident between flow conditions with and without the HHD and Tacoma Public Utilities projects. Median flow values were lower and there was an overall downward shift in flow distributions for the with-projects scenario. These effects apparently result from the diversion of up to 113 cfs from the river by the TPU project and from the reduction in flood peaks due to HHD.

One of the two original congressionally authorized purposes for HHD was low flow augmentation. The analysis indicates that flow augmentation by HHD does not fully overcome the flow reduction effects of the Tacoma diversion during low flow periods. The low flow conditions in the river last longer than they would without the projects in place and the annual minimum flow tends to occur two weeks earlier than without the projects.

Flood flows were substantially lower under the with-projects scenario. Peak flows in the 1964-1995 period likely would have ranged up to 29,000 cfs without the projects in place (based on the natural flow simulation), and 16 percent of the annual peaks would have been expected to be greater than 11,000 cfs at Palmer. With the projects in place, no annual peak flows have exceeded 11,000 cfs. Managed flood peaks also lasted for longer periods of time under the with-project scenario, albeit at greatly reduced levels.

The effects of the two projects are summarized in Table Hydro-ES1 below.

Table Hydro-ES1. Summary of "Natural Flow Analysis" Findings.		
Hydrologic Characteristic	**With Projects**	**Potential Ecological Implications**
Annual minimum and summertime low flows	Flows less than 302 cfs occured 49percent more often and summertime means and annual minimum extremes were consistently longer	• Reduces spatial habitat for rearing • Decreases water depth in riffles, glides and pools. May constrain upstream adult chinook migrationReduces water velocity, may be constraining downstream juvenile movement (e.g., outmigrant survival rates of coho tend to decrease with decreased flows)Shallower water can lead to higher temperatures where temperatures already can exceed salmon preferences in the Green River • Decreases wetted width of river available for spawning, forcing chinook to spawn closer to the thalweg, where scour potential is generally greater. • May create adult chinook passage problems from mainstem into Newaukum Creek
Timing of annual minimum flow	The annual minimum flow occurred two weeks earlier, in late August rather than mid-September	• May affect timing of upstream adult migration • May create warmer, more stressful instream conditions where temperatures already can exceed salmon preferences
Annual maximum flows (flood peaks)	Flood peaks were reduced, with no flood flows above 11,000 cfs at Palmer with the projects in place (compared to one day flows ranging up to 18,000+ cfs without projects (and peak flows even higher) and exceeding 11,000 cfs in 1 out of every 6 years)	• River has less ability to create new side channel habitat, reducing habitat for salmon as well as recruitment of gravel from the floodplain • River has less ability to maintain existing side channels • River has less ability to recruit wood into the channel, reducing overall habitat quality • River margin habitats are less dynamic and becoming artificially stable, reducing gravel recruitment from stream margin
Flood durations	Durations of moderate flood flows (greater than 5925 cfs) were longer by 39percent	• May increase frequency or duration of scour of river bed gravel. Effects are compounded as fewer side channels (where scour would be less) are being created so more of the population spawns in the mainstem

KEY FINDINGS: IMPACTS TO SALMONIDS RESULTING FROM HYDROLOGIC ALTERATION

UPPER GREEN RIVER SUB-WATERSHED (RM 64.5 TO HEADWATERS)

Upstream Migration

- Subsurface flows have been observed in the North Fork Green River during late summer (Noble 1969; Hickey 2000b), and could prevent salmonids from entering the river or moving upstream. Operation of the North Fork well-field by Tacoma could reduce flows in the North Fork, although there is currently insufficient data on the extent of this potential impact.

Spawning and Incubation

- One model suggests that timber harvest related disturbances have been extensive enough to cause peak flow increases capable of modifying channel conditions (USFS 1996; O'Connor 1996; Wetherbee 1997) and mainstem reaches just upstream of the Lester WAU have recently experienced scour to a depth sufficient to cause redd mortality during high flows (Fox and Cupp 1996).

- The inundation of up to 7.7 miles of mainstem and tributary habitat has resulted in lower water velocities, decreased oxygen levels, and increased sediment loads in the redd environment, which can result in embryo and larval mortality. The associated decrease in temperature with the increase in water depth can result in a delay of egg maturation.

- Howard Hanson Dam and the Headworks Dam have resulted in the inaccessibility of over 100 miles of combined mainstem, tributary and side channel spawning habitat to anadromous salmon.

Juvenile Rearing

- Construction of HHD has resulted in a net loss of 7.7 miles of mainstem and tributary rearing habitat (side channel habitat undetermined) due to inundation when operated at full pool. This area has been converted into rearing habitat that fluctuates unnaturally from a lake to free flowing depending on flood control responsibilities.

Downstream Migration

- Downstream migrating salmonid smolts, especially chinook, are delayed within the reservoir behind HHD and subject to increased mortality in the reservoir and through the dam bypass pipe and gates.

MIDDLE GREEN RIVER SUB-WATERSHED

Upstream Migration

- Since 1913 the Tacoma water withdrawals at the Headworks have lowered summer low flows in the mainstem. Howard Hanson Dam summer low flow augmentation (since 1964) has helped to increased these flows but not to natural, pre-diversion levels. Low flows in the late summer have only met instream flow requirements 9 out of the last 30 years (30percent). Tacoma's First Diversion Water Right Claim (FDWRC) of 113 cfs is not constrained by these minimum instream flow requirements.

- Refill of the HHD conservation pool in the spring has historically prevented or truncated spring freshets. The lack of freshets, especially during the spring reservoir refill period may delay steelhead upstream migration.

Spawning and Incubation

- Alterations in the natural flow regime during HHD refill operations may adversely impact spring spawning and incubation success in off-channel habitats that become disconnected.
- The dam flood flow manipulations result in an increase in the duration of flows that scour spawning gravel from the streambed.
- Late summer flows downstream of the Headworks (1911) diversion compel many chinook to spawn towards the thalweg rather than the margins, increasing the probability of egg loss due to streambed scour during higher winter flows.
- Late summer low flows and associated shallow water over many riffles increase the energy expenditure of upstream migrating adult chinook.
- Late summer low flows and associated shallow water can reduce the number of chinook that spawn in the downstream ends of side channels.
- Summer low flows increase the difficulty adult chinook have moving from the Green River into major spawning tributaries such as Newaukum Creek.

Juvenile Rearing

- Lower than normal summer low flows have reduced the amount of rearing habitat and exacerbated high summer water temperatures.
- Refill operations at HHD have reduced the frequency of side-channel connectivity, which would increase the probability that juvenile salmonids may become stranded in side channels that become disconnected from the mainstem. Juvenile chinook have been observed utilizing side channel habitats in the mainstem during the spring (Jeanes and Hilgert 2000).

Downstream Migration

- Spring refill operations at HHD have reduced flows and prevented spring freshets, prolonging downstream migration of juvenile salmonids. This makes juvenile salmonids more susceptible to predators and adverse water quality conditions. Green River Hatchery chinook smolt releases have been shown to have higher survival to the Duwamish with increasing flow; only 40 percent of the smolts released survived when flows were approximately 650 cfs at Auburn, while survival rates between 70 and 100 percent were observed at flows higher than 2,000 cfs (Wetherall 1971).

LOWER GREEN RIVER SUB-WATERSHED

Upstream Migration

- The diversions of the White River and Cedar/Black Rivers altered the migration routes of upstream migrating salmonids

- The combined diversion of the White River and Cedar/Black Rivers reduced the drainage area of the Green River basin by almost 60 percent. Diversion of the White River reduced summer flows in the lower Green River basin by roughly 50 percent. This results in the loss of physical habitat area such as size of pools, depth of riffles and an increase in temperature .that could delay migration and harm fish.

Spawning and Incubation

- Alterations in the natural flow regime during HHD refill operations may adversely impact spring spawning and incubation success by disconnecting off-channel habitats. .

Juvenile Rearing

- Low summer flows adversely impact the amount of rearing habitat and increase high summer water temperatures.

- Juvenile chinook, coho, steelhead, chum and cutthroat salmonids have been observed utilizing side channel habitats in the mainstem during the spring (Jeanes and Hilgert .2000). Refill operations at HHD have reduced the frequency of side-channel connectivity, which would increase the probability that juvenile salmonids may become stranded in side channels that become disconnected from the mainstem.

- The diversion of the White and Cedar/Black Rivers and construction of revetments reduced the channel width and caused the Green River to form a new, lower floodplain, cutting of access to former off-channel rearing habitats.

- The amount of urbanization increases the frequency, magnitude and duration of stormwater runoff that adversely impacts salmonid rearing habitat.

KEY FINDINGS--MAJOR TRIBUTARIES

Upstream Migration

- The affects of urbanization and groundwater withdrawals have reduced summer low flows, which may delay the upstream migration of adult chinook salmon in Newaukum and Soos Creeks.

Spawning and Incubation

- Impervious surfaces resulting from urbanization increases the volume of stormwater discharged into a stream for a given storm event. This action increases the height of peaks and creates new peaks where none previously existed, potentially increasing the frequency of scouring and deposition. This further reduces egg and alevin survival.

Juvenile Rearing

- Increases in urbanization and groundwater withdrawals have reduced summer low flows, reducing the amount of available salmonid rearing habitat and exacerbating increases in summer water temperatures (water quality degradation).

- As urbanization increases, the volume of stormwater discharged into a stream for a given storm event also increases. This action increases the height of peaks and creates new peaks where none previously existed potentially increasing the downstream displacement of emergent fry and reducing quality of overwintering habitat.

DATA GAPS

- There is little information available to assess the historic impacts of operation of Tacoma's North Fork well field on fish passage in the North Fork Green River

- The results of the trial "Natural Flow Analysis" suggest several data gaps where additional research into flow records and/or records of operations may improve these conclusions. Two of the most important are listed below:

  - Howard Hanson Dam operations--The analysis of managed conditions is wholly based on the measured flows at Palmer over the period of record, even though HHD operations have changed during that time period. In particular, changes in spring refill timing and flood ramping rates may have an impact on downstream hydrologic conditions. The model could be revised to clearly define HHD operating guidelines and simulate managed conditions over the entire time period as if current operations had prevailed.

  - TPU flow diversion records and protocols--Review of diversion records would improve the evaluation of diversion impacts during extreme low flow periods by isolating the effects of the diversion from HHD flow augmentation operations. From a comparison of mean monthly flows for with-and without-projects conditions, it is clear that the entire 113 cfs diversion right was not always implemented.

METHODS AND APPROACH

Hydrology (referring to the quantity and movement of water through an ecosystem) is one of the principal processes responsible for creation and maintenance of aquatic habitat. The volume of water in the Green River and its tributaries at various times during the year, and the degree to which this has been altered by development, operation of dams, and other practices, has profound implications for salmonid population viability. This chapter describes current and historic conditions in the Green River watershed, with a principal focus on the mainstem Green River and major tributaries. The potential effects of proposed projects and possible future landuse changes that may alter hydrologic conditions in the future are not considered here.

Two principal approaches have been taken to evaluating the hydrology of the Green/Duwamish River River. The main body of this report describes existing and historic conditions based on information contained in previous studies and literature and the report addendum describes a trial approach to analyzing natural streamflows in the Green River. Together, the results of these approaches were used to identify and evaluate hydrologic impacts on fish.

In the past, efforts to protect aquatic species from hydrologic impacts have largely focused on the setting of minimum instream flows. Recent research however, emphasizes the importance of the entire hydrologic cycle within which salmonids (Richter et al. 1996; Poff et al. 1997). This view considers the evolved range of flow variation in a naturally flowing river: the magnitude, frequency, timing, duration and rates of changes of various individual and seasonal flow events. Thus, both the literature based review and the trial natural flow analysis conducted for the Green River were designed to evaluate this broad range of flow characteristics.

To facilitate these analyses, the mainstem Green River Basin has been subdivided into five sub-watersheds: 1) the Upper Green River sub-watershed (upstream of the HHD at RM 64.5); 2) the Middle Green sub-watershed (RM 32 to RM 64.5); 3) the Lower Green River sub-watershed (RM 11 to RM 32); 4) the Green/Duwamish Estuary (downstream of RM 11); and major tributaries (Soos Creek and Newaukum Creek) (Figure HYDRO-1). This partitioning reflects divisions of the system by both natural and human influences, and to a certain extent, by fish use.

The following sections discuss major hydrologic impacts to the mainstem Green River drainage area by sub-watershed. Impacts are generally classified as occurring due to flood control projects, water use or land use activities.

RESULTS

UPPER GREEN RIVER SUB-WATERSHED (RM 64.5 TO RM 93)

WATER USE AND DIVERSIONS

The Upper Green River sub-watershed is primarily forested, with few residences and virtually no residential development. The primary water use in the upper watershed consists of the City of Tacoma’s (Tacoma) North Fork Well field. The following discussion of the North Fork well field was provided in a draft HCP recently completed by Tacoma (Tacoma 1999).

Tacoma operates a well-field that taps the North Fork Green River Aquifer, using the water to partially replace surface flows when the turbidity of the Green River reaches 3 NTUs and completely replace surface flows at turbidity levels of 5 NTUs or greater. The well field, developed in 1977, consists of seven wells that can be used to withdraw water from an unconfined aquifer at depths ranging from 65 to 103 feet. Water from the well field is pumped into a pipeline that flows into a 10-million gallon reservoir located near the Tacoma Headworks facility.

The well field is used to replace surface water withdrawn from the Green River at RM 61.5 when turbidity in the river is high. High turbidity in the Green River usually occurs in association with high runoff and increased stream flows, thus use of the well-field generally coincides with high flows in both the mainstem Green and North Fork Green River during the winter and spring. Over a five-year period in the 1960s, periods of high turbidity (>5NTUs) in the Green River, during which withdrawal from the well field would be required, averaged 85 days per year (Table Hydro-1). Periods when well use would have been required have occurred in September; however, those September turbidity events occurred when flows in the North Fork and mainstem Green River were high (Noble, 1969).

Table HYDRO-1. Summary of Average Daily Flow in the North Fork Green River and Expected Well Demand from the North Fork Well Field by Month.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Avg. Daily flow(cfs) [1]	147	124	92	117	121	73	26	12	24	38	96	169
Days of well use (avg) [2]	15.2	10	6.2	8.8	11	5.4	0	0	2.6	2.4	10.2	13
Days of well use (range)	4-25	0-28	0-18	0-23	0-20	0-20	0	0	0-13	0-4	7-13	7-19

[1]Mean average daily flow at USGS gage 12105710 North Fork Green River near Lemolo, Washington for the period from July 1965 to September 1982.

[2]Average number of days per month that well use would be required, based on the number of days when turbidity exceeded 5 NTU's measured at the Headworks over a five year period in the 1960's (Noble 1969).

The North Fork Green River aquifer is fed by water that infiltrates from the North Fork Green River from where it enters the broad valley of the ancestral Green River (approximately RM 3.0) until the point where the stream intersects the water table near the well field. The recharge rate is directly related to river stage in the North Fork Green (Robinson, 1974). The mean discharge of underflow is estimated to be 60 cfs (Noble, 1969), and may reach as much as 150 cfs during winter months (Robinson, 1974).

Withdrawals from the well field are limited to the quantity available from aquifer underflow plus depletion of aquifer storage (Noble and Balmer, 1978). The aquifer is small, and recharges quickly during wet periods. However, the infiltration rate is less than the aquifer transmissivity rate, and the wells are thus able to fully intercept the underflow (Noble and Balmer 1978). The small amount of aquifer storage and lack of recharge limits the North Fork well field as a source of water during dry periods when flows in the North Fork Green River are low. Operation and testing of the wells indicates that the well field can sustain approximately 60 million gallons per day (93 cfs) under very wet conditions where recharge of the aquifer occurs at a high rate during the pumping period, and can probably sustain 24 million gallons per day (37 cfs) continuously under all except the driest conditions.

Investigations of the lower North Fork Green River have shown that the majority of flow within the reach downstream of the North Fork well field is supplied by emerging groundwater during the late summer and early fall (Noble 1969). As surface flows decline, the proportion of flow provided by underflow increases, and in extreme cases may maintain flow within the lower North Fork Green River channel even when upstream reaches are dry. Instream flows supplied wholly or partly by groundwater outflows provide habitat and temperature refugia for fish during the late summer and fall low flow period.

FLOOD CONTROL

Howard Hanson Dam is a federally funded and operated flood control project on the Green River located at RM 64.5, and spans an area of the Green River downstream of Eagle Gorge[1], a narrow canyon with nearly vertical rock walls. Construction began in February 1959, and the dam went to operation on Christmas Day of 1961[2]. Construction of Tacoma's Headworks Diversion Dam (Headworks) in 1913 had blocked upstream fish passage at RM 61.5, approximately three miles downstream from HHD, thus no upstream fish passage facilities were originally incorporated into HHD.

HHD is a subsidiary earth-filled structure composed of rolled rock fill, sand and gravel core, drain zones, and rock shell protection (USACE 1998). The dam is 960 feet thick at the base decreasing to 23 feet thick at the crest. The embankment is 235 feet high and 500 feet long and has an inclined core of sand and gravel material. The total length of the dam, including the spillway and abutments, is 675 feet.

The intake structure includes trashrack bars, a deck for debris removal, one tractor type emergency gate, and gate hoist equipment located in the gate tower. The outlet structure consists of a gate tower and intake structure with two tainter-type gates, a concrete horseshoe-shaped outlet tunnel, a gate-controlled bypass, and a stilling basin. The 900-foot-long, 19-foot-diameter flat bottom horseshoe-shaped outlet tunnel passes normal flow released for project regulation. The tunnel is controlled by two 10-foot-wide by 12-foot-high regulating tainter gates at the bottom of the reservoir pool (elevation 1035 feet) above mean sea level (MSL). Low-flow releases during the summer conservation period are made through a 48-inch bypass intake located about 35 feet above the bottom of the pool. This outlet has a capacity of approximately 500 cfs at maximum conservation pool (elevation 1141 feet). Flows are regulated manually by adjusting gate controls at the dam under direction of the U.S. Army Corps of Engineers Water Management Section.

The gate-controlled spillway is anchored in rock on the left abutment and in a concrete monolith adjacent to the embankment. The spillway is a concrete ogee overflow section with two 30-foot-high by 45-foot-wide tainter gates to control major flood flows and prevent overtopping of the dam. The lowest elevation of the gates is 1,176 feet. The downstream chute has a curved alignment and is paved for a distance of 712 feet downstream from the weir. The tainter gates

[1] Eagle Gorge was a canyon located about 1.75 linear miles (not RM) southeast of Howard A. Hanson Dam.

[2] USGS Water Data Reprt WA-96-1, p. 178, reports that the earth-fill dam was completed 31 March 1962, and that "storage began Dec. 5, 1961."

permit storage to elevation 1,206 feet without spillway discharge. The maximum spillway discharge is 115,000 cfs at the spillway design flood pool elevation. In an extreme flood situation, water can be released over the spillway through the gates. To date, use of the spillway has not been required.

The reservoir behind the dam collects runoff from the 220 square mile Upper Green River Basin. In normal years, the reservoir is drawn down to an elevation of about 1070 feet in November when the summer low flow period is obviously over, significantly reducing the pool area. During winter, the reservoir is kept nearly empty, and the river flows through the gate-controlled outlet tunnel at the dam's left abutment. Howard Hanson Dam was designed to provide flood protection up to the 500-year event or the equivalent of a peak inflow to the reservoir of 65,000 cfs, and provides 106,000 acre-feet of flood control storage. The reservoir is kept as low as possible during the late fall and winter flood season to maximize flood control storage, thus during that time HHD is essentially a run-of-the-river facility. As the river rises during storm events, water is impounded. During flood regulation, the project is typically operated to limit flows at Auburn below 10,000 cfs as inflows to the reservoir are rising, and to below 12,000 cfs as inflows recede. As inflows to the reservoir decline, the water impounded in the reservoir is released at a rate sufficient to prevent a drastic drop in the stage in the river downstream, which could result in bank sloughing or fish stranding. The details of HHD operational requirements are found in Table HYDRO-2 and Appendix HYDRO-1. Flood control operations are conducted in accordance within the parameters of the project's congressional authorization. (so there is little flexibility to operate for other purposes during the flood season.)

Table HYDRO-2: General Ramping Guidelines Followed by the Army Corps of Engineers for Operation of HHD.

Tailwater change	No more than 1 foot/hour. Attempt to limit to 0.2 feet/hour during normal operations.
Auburn stage	Attempt to limit Auburn stage drop to 1 foot/day during recession.
Refill considerations	Attempt to follow WDFW guidelines for ramping criteria.

The probability of flooding greatly diminishes by late February, and the dam begins its second major function: water conservation. Usually, the reservoir begins to fill in mid-April to a maximum pool elevation (1141 feet), to provide summer and early fall low flow augmentation. At full pool (1141 feet), the reservoir inundates approximately 4.5 miles of mainstem Green River habitat, and about 3 miles of stream habitat in the North Fork Green River and other tributaries.

The original authorization of HHD provided for fishery enhancement by storing water through the summer, then releasing it to augment low flows occurring in the late summer and fall. The low flows are a result of seasonal variation and water withdrawals such as those shown in figure Hydro-4. Historically, refill of the reservoir usually began between late April and June. In recent years, the start of refill is determined each year depending upon conditions of that specific water year. The Army Corps of Engineers coordinates refill with federal, state and local fisheries agencies, the Washington Department of Fish and Wildlife and the Muckleshoot Indian Tribe.

During refill, outflow is reduced and the reservoir allowed to partially fill to elevation 1141 feet in order to provide a summer conservation pool for low flow augmentation. The reservoir contains approximately 25,000 acre-feet of water at this elevation, which is the amount of water needed to assure flows of at least 110 cfs at Palmer (downstream of Tacoma’s diversion) with 98percent reliability. Filling the reservoir above elevation 1141 is not regularly practiced, as this inundates otherwise dry upstream habitat. Filling also affects downstream habitat by interrupting the natural river flow regime.

In combination, HHD and Tacoma’s Headworks result in the loss of anadromous salmon accessibility to 29.8 miles mainstem and 6.9 of mainstem side channels as well approximately 70 miles of tributary channels. All but 3.3 miles of mainstem and 2.8 miles of tributary habitat is located upstream of the HHD (J. Cutler pers comm. 1999). Since 1980, juvenile salmonids have been released into the Upper Green River sub-watershed. More recently, at temporary adult fish trap has been constructed on the right bank at the Headworks. This trap is used to capture adult steelhead for transport upstream of HHD and artificial propagation. A detailed description of up and downstream migration and passage barriers associated with these projects is provided in the Fish Passage chapter of this report.

A small storage pool is maintained behind the dam year round, including during the winter drawdown, to capture suspended sediment. This storage pool is called the turbidity pool, and it currently permanently inundates approximately 1.8 miles of stream habitat, including 1.5 miles of mainstem channel (USACE 1998). At the normal summertime high pool elevation of 1141 ft MSL, the reservoir inundates approximately 7.2 miles of stream habitat. The average total length of time the pool is held at or above 1141 ft is 79 days, and generally occurs between May 15 and July 30. The reservoir pool may be filled to a maximum elevation of 1147 feet MSL for debris collection, and is typically at that level for approximately two weeks (USACE 1998).

Inundation converts formerly free-flowing stream habitats to lake-like conditions during flood control operations and spring refill. Water depth increases, water velocity is reduced, and the temperature regime and dissolved oxygen content change. The primary effects of inundation are a substantial reduction in vegetative cover, bank stability and the number and structure of pools, and an increase in the amount of fine sediment in riffles (Wunderlich and Toal 1992).

In addition to inundating habitat formerly used by anadromous and resident fish, operation of HHD has modified physical habitats in portions of the river that are seasonally free-flowing. Physical habitat alterations are discussed in the Hydromodification chapter of this report.

LANDUSE

Since 1914, when the City of Tacoma entered a cooperative agreement with the federal government for the purpose of protecting the City’s water supply, access to lands owned by Tacoma in the upper basin has been limited, except for fire protection, forest management activities and to provide access to United States Forest Service (USFS) lands. Lands managed by the USFS in the upper watershed may be accessed via Stampede Pass, and are currently used primarily for recreation.

Removal of forest vegetation can cause changes in the amount of precipitation that reaches the ground and in the rate of snowmelt (Harr et al 1975; Troendle and King 1985; Haupt 1979; Harr 1981). Roads and skid trails convert subsurface flow to surface flow and compact the soil, increasing surface runoff (Megahan 1983). Using a model that predicts flow increases based on the amount of mature forest cover by elevation zone, and local climatic data, the WDNR watershed analyses completed for the Lester, Upper Green and Sunday Watershed Administrative Units (WAUs) in the Upper Green River sub-watershed suggested that few tributary basins had experienced peak flow increases greater than 10 percent as a result of existing timber harvest operations (O'Conner 1996; Wetherbee 1997). Draft analyses completed to date for the Howard Hanson/Smay WAUs reach the same general conclusion (Ryan 1999). Ten percent is generally considered the threshold of concern for peak flow increases according to the DNR Watershed Analysis hydrology model.

In contrast, the Mount Baker-Snoqualmie National Forest (MBSNF) uses the amount of disturbed area in a basin to determine whether increased peak flows have the potential to alter channel conditions. Based on an empirical relationship that suggests peak flow increases which impact stream channels occur when 12 percent of a drainage basin has compacted soils (i.e. roads and skid trails), the MBSNF has determined that harvest-related disturbance within the Upper Green River sub-watershed is extensive enough to cause peak flow effects in a number of subbasins (USFS 1996). Increased peak flows, particularly in combination with high sediment supply, increase the risk of bed scour. While the results of these assessments are somewhat contradictory, mainstem reaches just upstream of the Lester WAU have recently experienced scour to a depth sufficient to cause redd mortality during high flows (Fox and Cupp1996).

MIDDLE GREEN RIVER SUB-WATERSHED (RM 32 TO 64.5)

WATER USE AND DIVERSIONS

The principal consumptive use of water from the mainstem Green River is the City of Tacoma municipal water supply accounts for 57percent of the Green River surface water rights (Figure HYDRO-4). Tacoma began diverting water from the Green River in 1913 with the completion of the Headworks. Tacoma's average diversion increased from 62 cfs in 1913 to about 100 cfs in 1953, and has remained at that level since 1953. Water is continually diverted from mainstem Green River except at times of excessive turbidity (>5NTU's), when Tacoma uses groundwater pumped from its North Fork Green River well fields. In 1985, Tacoma was granted a Second Diversion Water Right (SDWR) to an additional 100 cfs. Water available under the SDWR has not yet been utilized. Other consumptive water uses, including mining and irrigation, represent the remaining 43percent of allocated water rights in the mainstem (Figure HYDRO-4).

Tacoma provides approximately 62 million gallons of water per day to nearly 83,000 customers in Tacoma, Pierce and King Counties (Tacoma Water 1999). Commercial and industrial customers use the majority of Tacoma's municipal water supply (Figure HYDRO-4), and one customer, the Simpson Tacoma Kraft Company, accounts for the majority of commercial/industrial use (65percent of Commercial/Industrial; 33 percent of total) (Tacoma Water 1999). As a result of a severe drought in 1987, Tacoma Water increased its focus on water conservation. In 1998, average daily consumption was down 15 percent from 1989 levels, despite a 10 percent increase in customers (Tacoma Water 1999).

A comparison of the actual measured flows at Palmer and Auburn with the projected natural flows over the period from 1964 to 1996 indicated that the average seven-day low flow was 18 percent lower than it would have been without the Diversion and HHD at Palmer, and 7 percent lower than it would have been without the Diversion and HHD at Auburn (Table HYDRO-3). While changes in climate and inflows from tributary streams may have influenced these flows, much of this decline can probably be attributed to Tacoma's diversion. Preliminary results also indicate that timing of minimum flows in the vicinity of Palmer has become more variable, and now occur in the first week of September as compared to the third week in September under the natural flow regime (D. Hartley, 1999). The addendum to this chapter contains a detailed comparison of the modeled natural and with-project flow regimes.

Table HYDRO-3: Estimated natural and regulated seven-day low flow and annual minimum flow for the period of 1964 to 1996, compared to the actual flow at the Auburn and Palmer USGS gages on the Green River, Washington.

	Auburn Gage	Auburn Gage	Palmer Gage	Palmer Gage
	7-day Low Flow (cfs)	Annual Minimum (cfs)	7-day Low Flow (cfs)	Annual Minimum (cfs)
Actual	249	242	118	114
Natural	268	225	144	112
With HHD/without Tacoma Diversion	278	---	134	---

In 1980, the WDOE (Chapter 173-509 WAC) established instream flow restrictions on the mainstem Green River at USGS gage stations near Auburn (12113000) and Palmer (12106700). Instream flow recommendations were developed based on a study conducted by the USGS that identified correlations between low summer flows and adult salmon and steelhead returns (Swift 1979). Required instream flows at Auburn range from 300 cfs during the late summer to 650 cfs from December 1 through June 14 (Table HYDRO-4). Instream flows at Palmer range from 150 cfs to 300 cfs (Table HYDRO-4). Tacoma's First Diversion Water Right Claim (FDWRC) of 113 cfs is not constrained by these minimum instream flow requirements. However, in recent years, Tacoma has attempted to work cooperatively with resource agencies and the Muckleshoot Indian Tribe (MIT) to reduce impacts of water withdrawals on fish and other instream resources.

Table HYDRO-4: Instream Flow Requirements at the USGS gage at Auburn (USGS # 12113000) and Palmer (USGS # 12106700) under Ecology's Instream Resource Protection Program.*		
Season	**Auburn**	**Palmer**
June 15 to July 14	550 cfs	150 cfs
July 15 to September 15	300 cfs	150 cfs
Sept. 16 to Sept. 30	300 cfs	150 cfs
Oct. 1 to Oct. 15	300 cfs	190 cfs
Oct. 16 to Oct. 31	350 cfs	240 cfs
Nov. 1 to Dec. 1	550 cfs	300 cfs
Dec. 1 to June 14	650 cfs	300 cfs
* These requirements may be modified during critical drought years (<1 in 10 low-flow frequency) as specified in WAC 173-509.		

FLOOD CONTROL PROJECTS

Howard Hanson Dam

Prior to construction of HHD, flows as high as 28,000 cfs were measured at the Auburn gage (USGS 1996). The natural bankfull flow (approximately 2 year return interval) in the Green River at Auburn was about 12,000 cfs (Dunne and Dietrich 1978). Since construction of HHD, there has been almost a complete absence of flows above 12,000 cfs at Auburn due to flood control operations (Figure HYDRO-5), and the two-year return interval event has decreased by 24 percent, to approximately 9,100 cfs (Figure HYDRO-6). At the same time, the duration of flows between 3,500 cfs and 9,000 cfs has nearly doubled (Figure HYDRO-7).

Large floods are generally responsible for creating the diverse habitats (e.g. gravel bars, backwaters, oxbows, sloughs) associated with large alluvial rivers such as the middle Green River. The absence of large floods has had a profound influence on habitat conditions in the unconfined portion of the mainstem in the Middle Green sub-watershed, which will be discussed further in Chapter 2.3 (Hydromodification). The absence of large floods also reduces recharge of shallow alluvial aquifers that are an integral component of floodplain ecosystems (Naiman et al. 1992). During floods, water is stored in sloughs and side channels, or seeps into floodplain soils, recharging groundwater storage. This stored groundwater slowly drains back to the channel, providing a source of cool inflow during the summer (Naiman et al. 1992).

Spring refill operations at HHD have historically reduced flows for several weeks between April and June; the timing of the flow reduction is dependent on hydrologic conditions in the upper watershed and USACE operating procedures (Figure HYDRO-8). As a result, the spring flows below the dam have been lower than historical conditions prior to construction of the dam (Figures HYDRO-2 and HYDRO-3). Past refill operations at HHD have also dampened or prevented spring freshets from passing through the system in some years (Figure HYDRO-8).

Decreased spring flows and the lack of freshets have affected the availability of off-channel habitats in the Middle Green sub-watershed. In a comparison of side-channel connectivity under natural and managed conditions, Coccoli (1996) noted that the frequency of connection between side channels and the mainstem under the modeled "natural" flow regime (i.e. without HHD or

Tacoma’s diversion) was higher than under both historic or current refill strategies. The length of time that side channels are disconnected from the mainstem has also increased as a result of reservoir operations (Coccoli 1996).

Water stored behind HHD during the spring is used to augment low flows during the summer. The average 7-day low flow at the Auburn gage prior to construction of HHD was 165 cfs, compared to 248 cfs since the dam has been in operation (Figure HYDRO-9). The 7-day low flow represents the average daily flow during the seven consecutive days with the lowest flows, and is conventionally used in evaluating low flows because shorter flow durations have much greater variability.

The annual 7-day low flow based on the modeled natural flow data indicate that instream flow requirements would not have been met during low flow periods in 28 of the 32 years (87.5percent) even in the absence of HHD and Tacoma’s diversion (Figure HYDRO-9). Actual flows measured at the Auburn gage have met or exceed minimum low flow requirements in only 9 of the last 30 years. Summer flow augmentation has helped maintain summer low flows in the Middle Green River, and, in the absence of Tacoma’s diversion, would be expected to increase the average seven-day low flow by approximately 7 percent at the Auburn gage (Table HYDRO-3). Model results indicate that the average seven day low flow at Palmer has been approximately 10 cfs less than would have occurred under the natural flow regime even with flow augmentation from HHD.

Levees and Channelization

Flood control levees can also alter the hydrologic regime. Large scale levees were built beginning in the early 1900’s to help prevent the floodplains of the lower Green River from flooding (see chapter 2.3). Periodic levee construction and maintenance activities have continued to the present, both to protect higher density population areas and specific residential areas. A recent survey of the lower Green River determined that levees and stream bank revetments were present on one or both banks along approximately 5.6 miles (40percent) of the mainstem Green River between RM 32 and RM 45 (Perkins 1993). The majority of these structures are located between RM 32 and RM 37.

Channelization and confinement of the channel between levees prevent high flows from accessing the floodplains, reducing groundwater recharge. Narrow, deeper channels have higher water velocity and bed shear stress, thus even small flood events may scour of bed materials. At the same time, simplification of the channel, including elimination of access to off-channel areas, reduces the availability of high flow refugia used by salmonids to escape the high velocity flows and the stability of spawning gravel. The physical effects of levees on channel processes and aquatic habitat is discussed further in Section 5.3.

LAND USE

The primary land uses in the Middle Green River sub-watershed are agriculture and rural residential development (see Chapter 1.1). Alternation of natural vegetation communities and compaction of soils has likely altered runoff patterns in the Middle Green River sub-watershed as much or more as in the Upper Green River sub-watershed. However, there is currently no data on the effects of landuse activities on the hydrology of the mainstem Green River downstream of RM 64.5. Changes in the hydrologic regime have been identified on the major tributaries to the Green River, Soos and Newaukum Creeks, and are discussed further in the section on major tributaries.

LOWER GREEN RIVER SUB-WATERSHED (RM 11 TO RM 32)

WATER USE AND DIVERSIONS

The White River, the Cedar/Black River and the Green River formerly joined together downstream of Auburn (Figure HYDRO-10). The combined flows of these rivers, at that time called the White River, meandered freely through the extensive low gradient Duwamish Bay geologic deposits, that dominate the lower basin topography (Dunne and Dietrich 1978). The lower White River channel was quite sinuous under historic conditions. The upper White River, a glacier-fed system supplying large quantities of sediment and summer flows, joined the Green River near RM 31. The combined flow of Lake Washington and the Cedar River fed into the White River at RM 11 through a short reach known as the Black River. Flooding was frequent throughout the lower basin. Below the Black River, the river flowed through a system of tidally-influenced marshes and swamplands. Broad, intertidal flats and shallows characterized the south end of Elliott Bay.

Both the White and Cedar/Black River were diverted out of the Lower Green River sub-watershed in the early 1900s (Figure HYDRO-10), resulting in significant changes to the hydrology of the Lower Green River sub-watershed. The combined diversion of the White River and Cedar/Black Rivers reduced the drainage area of the Green River basin by almost 60 percent, with the diversion of the White having a much greater impact upon the freshwater portions of the Lower Green than the diversion of the Cedar/Black. Historically, the White River was connected to the Puyallup River via an overflow channel known as the Stuck River. The entire flow of the White River was diverted to the Puyallup River in 1906 by a log jam that formed during a flood. Because of flood control concerns, a permanent diversion structure was subsequently constructed and completed in 1911, forcing the flow of the White River to continue discharging into the lower Puyallup River.

Because it is glacially fed, the White River tends to have higher summertime flows than other non-glacial systems in Puget Sound. Diversion of the White River reduced summer flows in the Lower Green River sub-watershed by roughly 50 percent. Sediment supply to the lower basin was also reduced sharply; the impacts of this reduction will be discussed further in Chapter 2.2 (Sediment Transport) The diversions enabled salt water from the estuary to move further upstream than before.

Ground water levels in the current White River valley are significantly higher than in the Green River Valley in the vicinity of Auburn and Kent (Pacific Groundwater Group 1999). The amount of flow from the White River groundwater system to the Green River was estimated to be approximately 34 million gallons per day (53 cfs) in September 1998 (Pacific Groundwater Group 1999). Flow during wetter times of the year has not been quantified, but might be expected to be greater. The study conducted by Pacific Groundwater Group (1999) indicates that the White River is a major source of aquifers that supply water to the City of Auburn.

The Black River, which enters the Green River at RM 11, was reduced to a small fraction of its former flow in 1916 by construction of the Ship Canal/Ballard Locks and associated lowering of the water level in Lake Washington. The Cedar River, which formerly joined the Black River, emptying westward into the Green River, was diverted into the Lake Washington to provide water flows for the locks.

FLOOD CONTROL

Howard Hanson Dam

The effects of HHD operations on the Lower Green River sub-watershed are similar to those described for the Middle Green River sub-watershed.

Levees and Channelization

As described previously, large scale levees were built beginning in the early 1900's to help prevent the floodplains of the lower Green River from flooding. Perkins (1993) determined that levees and stream bank revetments affected over 80 percent of the length of channel between RM 25 and RM 31. Levees are virtually continuous along both banks downstream of RM 25 (Fuerstenberg 1996).

Channelization and confinement of the channel between levees prevent high flows from accessing the floodplains, reducing groundwater recharge. Narrow, deeper channels have higher water velocity and bed shear stress, thus even small flood events may scour of bed materials. At the same time, simplification of the channel, including elimination of access to off-channel areas, reduces the availability of high flow refugia used by salmonids to escape the high velocity flows and the stability of spawning gravel.

LAND USE

Urbanization involves conversion of land and wetlands into residential, commercial, and industrial uses. In a compilation of data from 15 previous studies, Hollis (1975) showed a pattern of increased instantaneous peak discharge with an increased percentage of impervious area. Peak flows increases of 200 to 300 percent are typical of the changes resulting from low-level suburban development (10 to 20 percent impervious area) (Booth et al. 1990). In addition, the frequency of flows capable of transporting sediment and altering the channel configuration may increase by a factor of 10 or more (Booth 1991). At the same time, since water runs off impervious surfaces rapidly, groundwater recharge typically decreases. This results in a lowering of summer flows that are sustained primarily by groundwater.

Over 60 percent of the Lower Green River sub-watershed supports Urban/Residential land uses (King County 1999). Little data is available to document flow changes in the mainstem Green River resulting from increased stormwater runoff. However, estimated peak flow increases of over 2,000percent have been identified in a number of very small tributary basins with extensive urban development (Table HYDRO-5). Primary effects of urbanization on streamflows include increased peak flows and creation of new peaks where none previously existed in association with increased impervious area and diminished summer flows as a result of reduced floodplain storage.

Increased peak flows from tributary streams may exacerbate flooding in the lower Green River. Decreased tributary inflows during the summer will exacerbate low summer flows and high water temperatures in the lower Green River.

MAJOR TRIBUTARIES (SOOS AND NEWAUKUM CREEKS)

The largest tributaries to the Green River include Soos Creek, Newuakum Creek, Mill Creek and Springbrook Creek. The hydrologic regime of these major tributaries is dominated by winter rain events, with low flows occurring in the late summer (Figure HYDRO-10). The major tributaries are all located in the Middle and Lower Green River sub-watersheds, where the topography in typified by rolling hills formed on glacial deposits. Lakes and wetlands are common in the headwaters of each of these basins, and help sustain streamflows by slowly releasing groundwater during the summer months. The primary impacts on the hydrology of the major tributaries include stormwater runoff, urban development and consumptive water use.

WATER USE

Surface water rights and claims in the Soos and Newaukum Creek basins amount to approximately 27 and 10 cfs, respectively, and are predominantly for irrigation and small multiple domestic systems (Culhane et al. 1996). Groundwater withdrawals represent the largest water source in the major tributary basins. In the Middle Green River sub-watershed west of Palmer, thick glacial and alluvial deposits form aquifers with high water yields. The 1989 King County Ground Water Management Plan divides the lower and Middle Green River sub-watershed into four hydrogeologic sub-areas. These sub-areas include the Covington Upland, Des Moines Upland, Federal Way Upland, and Green River Valley (King County 1989). Water level declines have been observed in aquifers in the Covington, Des Moines, and Federal Way Upland subareas (King County 1989).

The three largest ground water supply areas in the Covington Upland are the Covington Water District Lake Sawyer Well field, King County Water District No. 111, and the Kent spring source (King County 1989). These municipal uses account for 67 percent of the groundwater rights issued in the Soos Creek Watershed. Municipal uses account for 56 percent of the total instantaneous water allocated in the Newaukum Creek basin (Culhane et al. 1996). Preliminary results from a USGS groundwater modeling study suggest that pumping even from deep aquifers in the region produces significant impacts on surface water bodies within the Green River basin (King County 1989).

Apparent declines in summer stream flow have been identified for the Soos and Newaukum basins, likely in response to increased urbanization, groundwater withdrawals and changes in precipitation (WDOE 1995). The average 7-day low flows in Soos and Newaukum Creek decreased significantly between 1968 and 1993 (Figure HYDRO-12).

LAND USE

An evaluation of the impact of future land use on basin hydrology conducted in the Soos Creek basin suggested that flood peaks could increase by an average of 180 percent over the 1985 conditions under the densest use permitted by existing or proposed land use or zoning (Table

HYDRO-5)(King County 1989). The same study indicated that under existing conditions the estimated highest peak flows occur in tributary basins with the greatest development, suggesting that urbanization has already impacted flood peaks in Soos Creek. Similar impacts are believed to have occurred in the Mill Creek basin, where the amount of impervious area was predicted to increase from 20 percent in 1985 to between 45 and 70 percent by 2,000 (King County 1986). In addition to increasing the magnitude and frequency of peak flows, more rapid stormwater runoff also affects summer low flows by reducing recharge of shallow groundwater aquifers that sustain flows throughout the summer. The decreased tributary flows exacerbate high water temperatures and decrease the quality and quantity of summer rearing habitat.

Table HYDRO-5. Modeled Peak Flow Increases and Extent of Impervious Area in Small Tributaries to the Green River, Lower Green Subbasin (RM 6.5 to RM 33).

WRIA Catalog Stream #	Stream Name	Location	D.A (mi^2)	Baseline Condition	Final Condition	Peak Flow Increase (%)	Impervious Area (%)	Source
-	Riverton Creek	LB, RM 6.0	0.68	Forested	1997	256% to 2222%	88% of area developed w/residential and light industrial	Entranco et al. (1997)
-	Fostoria Creek and nearby tribs	LB, RM 6.5-12	2.5	Forested	Max. build out	0-633%	Light industrial to low density residential	KCM (1986a)
0032	Gilliam Creek	LB, RM 12.7	3.0	1986	Max. build out	0-200%[1]	High density commercial residential to low density residential	KCM (1986b)
0051	Mill Creek	LB RM 23.9	22	1985	2000	ND	Increases from 20% to 45-70%	King County (1988)
0061	Olsen Creek	RB RM 28.6	1.6	Forested	1994	33%-91%	3% (EIA)[2]	Booth (1994)
0068	Cobble Creek	RB RM 30.05	0.26	1994	ND	ND	8% (EIA)[2]	Booth (1994)
0069	Lea Hill Tributary	RB RM 30.15	0.63	1994	ND	ND	12% (EIA)[2]	Booth (1994)

[1] For 2-year event
[2] EIA=Effective Impervious Area
ND=No Data

HYDROLOGY ADDENDUM--NATURAL FLOW ANALYSIS

INTRODUCTION

The purpose of this addendum is to document a trial analysis of the nature and degree to which Green River mainstem flows have been altered by two large public works projects--Howard Hanson Dam and the City of Tacoma's flow diversion at Palmer. These flow alterations have been evaluated at Palmer (RM 61), the upstream limit of the middle Green River, in order to focus on the effects of the operation of the dam and diversion. The analysis is most conclusive for the reach between Palmer and Auburn, where the effects of the two projects are predominant. The primary goals of this analysis are twofold: principally to determine whether such an analysis is practical and feasible for assessing hydrologic impacts on Green River ecology, and secondarily to identify ecological effects of these projects where they are clear from the analysis.

This addendum presents flow data with and without the dam and diversion in place, but makes no attempt to evaluate "historic" conditions prior to the White and Cedar Rivers being diverted from the watershed, or any landuse changes as a result of logging or other land management practices. Rather, all climate and land use conditions are consistent between the two flow regime data sets.

The objective of this analysis is to evaluate changes in all major aspects of the mainstem flow regime having the potential to affect ecological processes and habitat conditions in the Green River downstream of the two projects. Given the relatively new nature of this type of analysis, results are preliminary and the methodology should be viewed as a tool that can be modified to improve its relevance to evaluation of Green River ecology.

In the future, similar analytical techniques could be applied to other portions of the watershed. In addition, this technique could be developed into a flow management strategy resulting in managed flows that more closely resemble the natural flow patterns occurring in an unregulated river.

BACKGROUND

Recent ecological research, including guidance from the National Research Council, the National Marine Fisheries Service, and others, has indicated that all aspects of the flow regime have relevance for habitat protection (e.g. NRC, 1992; Poff, et. al., 1997). This view is summarized in the following statement from a report prepared for NMFS and the US Fish and Wildlife Service: "Protection of salmonid habitats requires stream flows to fluctuate within the natural range of flows for the given location and season" (Spence, et. al., 1996).

This is in direct contrast to current legal requirements in the State of Washington, which rely on establishment of minimum instream flows as the sole flow-related requirement for fish habitat protection. This research suggests that salmonids evolved with life histories reliant on the entire range of flow variation in a naturally flowing river: the magnitude, frequency, timing, duration, and rates of change of various flow events, annual maxima and minima, etc. The research further suggests that all of these aspects of the flow regime should be evaluated in examining hydrologic factors of decline for salmon production in the Pacific Northwest.

The impacts of hydrologic change can only be fully understood in concert with other factors of decline work. Changes in hydrologic parameters become more or less important depending on ecological and geomorphic factors such as gravel regime, wood loading and recruitment, and channel complexity within the river, the life histories of the species of interest, the degree to which various reaches have been altered by channelization and levee building, etc. Thus, these impacts will be better understood after they are integrated into the rest of the factors of decline analysis. In addition, some types of impacts that are expressed here as changes in flow rates can be more specifically quantified by integrating the flow analysis into available hydraulic modeling to assess changes in flow depths and habitat area.

The analysis presented in this addendum is based on two evaluation methodologies developed by several researchers at the Nature Conservancy to evaluate hydrologic change and to design flow management regimes to more closely mimic natural flow conditions (Richter, et. al., 1996, Richter, et. al., 1997). These methods, the Indicators of Hydrologic Alteration (IHA) and Range of Variability (RVA) approaches, were tested in a pilot analysis for the Roanoake River in Virginia. It is unknown whether these methods have as yet been applied to rivers elsewhere in the Pacific Northwest. However, the principal concept of analyzing changes in a suite of hydrologic characteristics selected to represent all major aspects of the flow regime, seems wholly appropriate for Northwest rivers. Opportunities may exist to modify the analysis to select the specific hydrologic characteristics with the most ecological importance in this region. With that in mind, the analysis described below should be viewed as a tool for evaluating hydrologic change and the results should be considered preliminary. It is hoped that ongoing dialogue between ecologists, hydrologists, and other scientists and managers working on Green River habitat conservation will improve the usefulness of this methodology.

In this analysis, a comparison of flow regimes representing both “natural” or without-projects conditions and “managed” or with-projects conditions was made using equal 32-year time spans of daily flow records. The gaging sites and time span were selected to determine the effects of the two major projects affecting the Green River flow regime: Howard Hanson Dam, which was completed in 1962 for the primary purpose of flood control, and the City of Tacoma flow diversion, which supplies municipal and industrial water and has been in operation since 1913. Howard Hanson Dam lies approximately 3.5 miles upstream of the Tacoma diversion site at RM 64.5.

The measured flow data record representing the with-projects (dams and diversion) condition is from the Palmer gage (USGS No. 12106700), which is located at RM 60.4[3], just downstream of the Tacoma diversion. This gage was selected because of its close geographic location to the Tacoma diversion and minimal tributary inflow between its location and that of the diversion. The period of record used for this analysis (1964-1995) begins immediately after completion of Howard Hanson Dam and commencement of flood control operations. The data representing “natural” or without project conditions were derived from a regression of measured inflow into the Eagle Gorge Reservoir above Howard Hanson for the same time period (CH2M-Hill, 1997). Because the record used is the entire historical data set since the dams and diversion have been in place, results reflect the entire range of operating protocols that have been used during that time frame. No attempt has been made to segment out differing operating regimes, or to modify the data to better represent the Corps’ current operating guidelines at Howard Hanson Dam (HHD).

IHA METHODOLOGY

The IHA (Indicators of Hydrologic Alteration) method uses a suite of biologically relevant flow statistics to characterize variability of a hydrologic regime and to quantify hydrologic alterations caused by human impacts by comparing regimes with and without the impact-causing projects in place. Richter et. al. (1996, 1997) suggested using flow regimes for pre- and post-project time periods to compare statistics derived from mean daily data. For this Green River analysis, however, statistics have been computed for measured and simulated flows over the same time period. This is intended to eliminate any climate- or land use-induced variation between the two data sets, and isolate the comparison to the projects.

[3] United States Geological Survey- Water Resources Data

In both situations, the data are then processed into 32 parameters for each year for both the with- and without-project flow records. The central tendency and variation of these inter-annual series are then estimated using means and coefficients of variation. This results in 32 means and 32 coefficients of variation for each data set. Absolute and percentage differences between each pair of analogous values along with their range of variability are then used to judge shifts in both the magnitude and variability of the 32 characteristics between the with- and without projects conditions.

The 32 flow characteristics calculated for each year include monthly means (12 statistics); 1-, 3-, 7-, 30-, and 90-day minimum and maximum flows (10); Julian Date of annual minimum and maximum daily flow (2); low flow and high flow pulses and durations (4); and counts and rates of flow rises and falls (4). These groups of characteristics are summarized below in Table Hydro-Add-1. Each of these characteristics have been linked in the literature to various river ecosystem functions, examples of which are stated in the table.

Table Hydro-Add-1. IHA flow characteristics and their ecological relevance.

IHA Statistics Group	Regime Characteristics	Hydrologic Parameters	Examples of Ecological Importance
Group 1: Magnitude of monthly water conditions	Magnitude Timing	Mean value for each calendar month	Habitat availability; Downstream migration rate and survival; Water temperature; Availability of spawning habitat; Access to side channels and tributary streams.
Group 2: Magnitude and duration of annual extreme water conditions	Magnitude Duration	Annual maxima and minima: 1-, 3-, 7-, 30-, and 90-day means	Floodplain recharge; Channel-forming flows; Sediment transport;Gravel recruitment from floodplain, gravel bars, and stream margins; Habitat availability; Wood recruitment from floodplain and stream margins; Degree of drought-induced ecological stress
Group 3: Timing of annual extreme water conditions	Timing	Julian date of each annual 1-day maximum and each annual 1-day minimum	Timing of key life history stages; Timing of outmigration.
Group 4: Frequency and duration of high and low pulses	Magnitude Frequency Duration	No. of high pulses each year; No. of low pulses each year; Mean duration of high pulses within each year; Mean duration of low pulses within each year	Impacts of dewatering and/or scouring of redds; Stranding of adult or juvenile salmonids; Connection to side channels
Group 5: Rate and frequency of water conditions change	Frequency Rate of change	Means of all positive differences between consecutive daily values; Means of all negative differences between consecutive daily values; No. of rises; No. of falls	Stress to aquatic organisms related to unusual rates or magnitudes of flow change
Adapted from Richter, et. al., 1996.			

In a refinement of the original method, Richter, et. al. (1997) introduced the Range of Variability Approach (RVA) in order to facilitate application of IHA to the problem of hydrologic restoration in managed river systems. Whereas the IHA identifies the degree of change in the aforementioned indicators, the RVA goes a step further to develop ranges for natural variation of each characteristic. The authors then recommend developing flow management protocols designed to better mimic the natural regime by limiting the discrepancies between frequency distributions of natural and altered IHA parameters.

The RVA concept defines a target envelope for annual values of each of the 32 characteristics based on without-project statistics. Adequacy of the with-project hydrologic regime is then evaluated as a percentage of years for which annual values of each characteristic fall outside the defined range. Richter et. al. (1996, 1997) referred to this percentage as the "Rate of Non-Attainment," as it used to determine to what degree the project is attaining its goals based on the RVA range. For this application on the Green River, this range will be referred to as the "Range of Typical Values;" that is the range of values that would be expected based on natural flow conditions. Richter et al (1997) does not suggest a method for identifying the appropriate range, and states that the range need not be consistent among the 32 flow characteristics. The implicit suggestion is that appropriate ranges for each variable are best selected based on the variable's influence on biological processes. Selection of appropriate ranges may be iterative and can likely be improved with further analysis.

Absent biological information to aid in prescribing the typical range, Richter, et al. recommends use of a range spanning 2 standard deviations--one on either side of the pre-impact mean (Richter et. al. 1997). Departures of the managed flow regime from the natural regime are then described by the percentage of years that the 32 characteristics fall outside the typical range. The Roanoke River is again used as an example using this default method of establishing variability ranges. No explicit guidance is given on what is an acceptable level limit in the number of values falling outside of the defined typical range. Similarly, no direction is given to check without-project non-attainment as a standard to judge with-project non-attainment by. In the case of the default definition of range, one might be led to believe that pre-project non-attainment is 32 percent, the case for data with a normal distribution. Normally distributed flow data would result in 68 percent of all values falling within the two standard deviation range (i.e. RTV), and 32 percent falling outside.

However, flow data are often not normally distributed, and frequently have no obvious underlying distribution. In cases where no obvious distribution exists, a common statistical procedure is to rely on non-parametric methods for further analysis. This involves ranking data and relying on medians and percentiles as descriptive measures rather than means and standard deviations. While this is a departure from the method described in Richter, et. al. (1996), it is valid based on standard statistical and hydrologic texts (e.g., Maidment, 1992). In this connection, any non-parametric range can be selected for comparison. Without biological information to suggest otherwise, the 16^{th} and 84^{th} percentile levels have been selected given their equivalency to a two-standard deviation range for normally distributed data. Comparison using this range provides a starting point for evaluating differences between with- and without-project flows. The ranges can later be adjusted as additional information becomes available regarding the effects of each of these flow characteristics on specific biological processes and functions in the Green River.
The analysis reported in this addendum relies exclusively on non-parametric methods. Methods using normal distributions as in the literature were found not to be statistically valid for many of the data sets. In a further refinement of this work, consideration should be given to reevaluating the appropriateness of a parametric approach to analyzing these data, perhaps using log-normal or some other distribution (the best distribution may differ by hydrologic parameter).

The use of the 16^{th} and 84^{th} percentiles for a variability range suggests that, by definition, 32 percent of the values for each parameter in the without-project data set will fall outside of the typical range. Changes in the number of values falling outside of this range for the with-project condition can thus be used to evaluate the degree of alteration resulting from the projects.

TRIAL APPLICATION OF IHA/ RVA TO THE GREEN RIVER AT PALMER

GENERATED "NATURAL" (WITHOUT-PROJECTS) FLOWS[4]

Natural flows were developed using an unpublished computer model developed by CH2M-Hill for the Corps of Engineers' Additional Water Storage project DEIS (CH2M-Hill, 1997). Natural flows (without projects) were derived from measured stage elevation changes at HHD. Given an estimate of the storage capacity for a range of water surface elevations and a rate of change, inflow rates were developed. These types of relationships are typically called rating curves. This method does have some drawbacks. If the rate of change in the inflow in any given day is significant enough, the estimated reduction in the inflow rate may be greater than the actual outflow from HHD, resulting in a negative computed flow rate. Obviously, this does not occur. To remove computed negative flow rates, they were first zeroed out, and then a smoothing function was applied. The smoothing function artificially reduces the value of extreme high flow events and increases computed extreme low flows. In contrast, using measured daily mean flow rates, the smoothing function is already partially done by representing flows that vary over the course of a day as an average flow rate. The smoothing function most adversely affects statistics associated with extreme single day values, thus 1-day annual maxima and minima were not used in this analysis. No attempt has been made to quantify this error, only to recognize it and limit the application of statistics as previously mentioned.

To account for the runoff that occurs between HHD and the Palmer USGS gage, a regression on the inflow to HHD and measured flows at Palmer for the period of record prior to HHD construction determined that "natural" flows at Palmer are typically equal to HHD inflows plus three percent. Thus, the without-project flows as computed (for the without-project data set) are equal to the measured inflows plus 3 percent for each daily mean.

With some slight variations to the IHA methodology, medians and Ranges of Typical Values were used for each hydrologic characteristic instead of means and standard deviations. The Ranges of Typical Values (referred to as RTV) falls between the upper 84^{th} percentile and the lower 16^{th} percentile threshold for each data set, which is consistent with the RVA methodology. The percentage of values falling within, or outside of these two thresholds, quantifies the magnitude of dispersion for a given data set. As with the RVA methodology, the number of data points above or below these thresholds are quantified. Distribution shifts between with- and without- projects conditions can then be identified based on the percentage of points falling in the upper (> 84^{th} percentile), middle (between the 16^{th} and 84^{th} percentiles), and lower (<16^{th} percentile) ranges. The RTV is defined as the middle range.

The overall degree of hydrologic change for a given characteristic is evaluated based on the change in the median value and the shift in the distribution as defined above. In order to evaluate the significance of this hydrologic change for a given characteristic, it proved useful to develop a consistent approach. This analysis in this paper uses an algorithm that can be critiqued and/or improved upon with future applications of this technique.

[4] Natural flows generated by CH2M-Hill

The approach used for this paper is as follows. A dual matrix is developed and used to convert the changes in median and distribution to a single number identified as the “Index of Hydrologic Change”. This provides a cumulative qualitative descriptor for all the various aspects of hydrologic change per element of the RTV methodology. To illustrate the process for categorizing a given set of changes in the median and distribution, an example of the method is illustrated in the figure below.

EXAMPLE: ESTIMATING THE INDEX OF HYDROLOGIC CHANGE

For this example, the index of hydrologic change is determined for the September monthly means. The first step is to quantify the percent change in distributions, relative to the without-projects condition. This percent change is separately determined for each of the lower, middle, and upper ranges, defined by less than the 16th percentile, between the 16th and 84th percentile, and greater than the 84th percentile, respectively. For the September monthly mean Group 1 statistic, the percent change in the middle range of distribution is 18 percent (whether the frequency increases or decreases within a given range is irrelevant for this calculation; the absolute value of the percentage change is used). The upper range shows zero percent change, the lower range shows an 80 percent increase in frequency. Referring to the left-hand matrix in Figure Hydro-Add-1 identified as Significance of Change in Distribution, the middle range changed greater than 15 percent and the lower changed greater than 30 percent. As a result, the significance of change in the distribution in September monthly means is considered “high.”

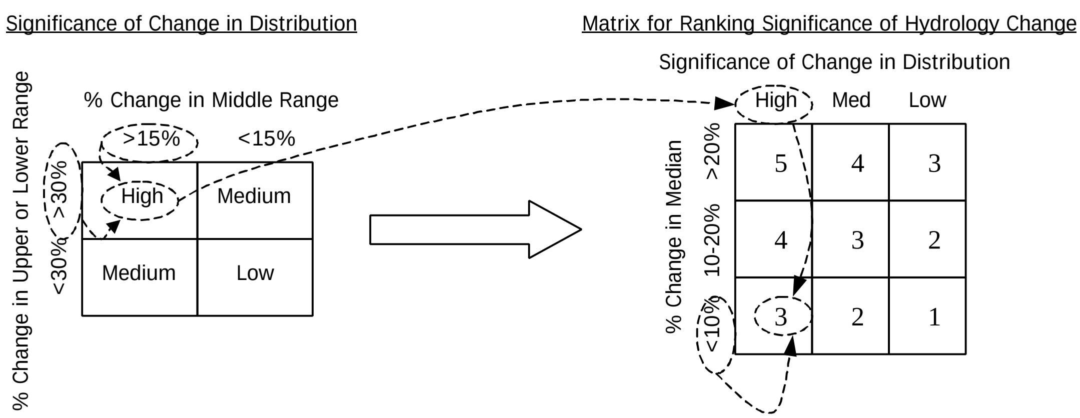


Figure Hydro-Add-1. Example for Identifying Index of Hydrologic Change.

The next step is to take that result and cross-reference it with the quantified percent change in the median value of September monthly means. For September, the median of monthly means decreased 6 percent. With these two factors of change, an index of hydrologic change value of 3 is used to characterize the overall change between without- and with-projects conditions. This index seems appropriate given that the shift in distribution is substantial while the shift in medians is slight at 6 percent. Thus, a moderate level of change is indicated.

Tables Hydro-Add-2 (which summarizes the difference between the with- and without-projects data) and 3 (which presents the specific results for the with- and without- projects data sets) represent the “IHA Report Cards.” These include the calculated statistical information--medians, 16th and 84th percentiles, etc.--that were used for comparisons. The remainder of the text refers to values that can be found in those tables.

ANALYSIS RESULTS

Monthly Mean Flows

The median flows for the monthly means from each data set show that the monthly flow regime of the river has shifted substantially in about half the months of the year. Most of the change is concentrated in the spring and summer months of May through August. This shift suggests only that the distribution of monthly means without and with projects has changed substantially, but gives little indication of how that change has occurred. To determine the nature of the change that has occurred, it is instructive to compare extremes, cumulative distributions of the monthly means, and the annual values of the IHA flow parameters.

Fall and Winter (October through February)

The median of the monthly means for October increases from 362 cfs to 420 cfs, or by 16 percent, when comparing with- to without-projects conditions. This suggests that HHD has successfully been augmenting low flows and/or releasing excess stored water at the beginning of the flood season. The magnitude of the Range of Typical Values (RTV) increased by 13 percent, indicating greater interannual variability than under natural (without-projects) conditions. November has only a slight increase in monthly flow rates with a 2 percent increase in the median (from 956 to 979 cfs).

The rest of the fall and winter months show a slight decrease (1 percent - 7 percent) in monthly means with medians ranging between 1073 and 1558 cfs for with-project conditions, and from 1124 to 1574 for without-project flows.

The magnitude of the RTV increases moderately (2 percent - 19 percent) for these months with December having the largest increase with 19 percent. This is associated with an increase in the dispersion of the flows at both ends of the range and not just a shift in one direction. The distribution of flows within both the upper and lower bounds increases by 20 percent. (see columns 6 and 8 in Table Hydro-Add-2). The presumption is that HHD operations may be slightly more variable in moderating the early winter storm events, which may include rain-on-snow events. It is somewhat surprising that this moderation would show up in the monthly means comparison, since the overall flood volume for a given event is not moderated, just the peak flow and timing. It is conceivable that with a longer time period of data and current reservoir operations information factored into the analysis, this increase in dispersion would be reduced. Even with all of these shifts in median and distribution, the Index of Hydrologic Change is not greater than 2 (on a scale of 1 to 5, with 5 representing the greatest change) for the fall and winter months (see Table Hydro-Add-2 column 9, “Index of Hydrologic Change”).

The degree of the impact of Tacoma’s flow diversion on fall and winter monthly means is somewhat unclear. It appears that the amount of water diverted from the Green River was far less than 113 cfs over large portions of the record, as the average flowrate throughout the entire record is only 82 cfs (55 mgd) less for the with-project condition than without the projects in place. This is based on an application of the continuity equation, weighting the average monthly differences by the numbers of days in each month.. This reduction in flow rate is less than 10 percent of the mean winter flow; however, it is proportionally higher in October and November.

The annual distribution of monthly means during this period has not shifted substantially, but a trend in the shifts is apparent (see Table Hydro-Add-2, columns 6 – 8) with either the distribution remaining similar to without-projects conditions or shifting into the lower range of flows (below the 16^{th} percentile).

TABLE Hydro-Add-2. Summary of Changes in With-projects Flow Conditions Data Relative to Without- Projects Conditions.

Upper Green River IHA, RVA Statistical Analyses		Summary of Change relative to Natural (without HHD or TPU) Median Difference		Change in RTV Range		Change in # of Excursions	Shifts in Distribution relative to Natural Conditions			Index of Hydrologic Change
Group 1:	Monthly Means	(cfs)	%	(cfs)	%	%Difference	Lower	Middle	Upper	5= High 1= Low
	January	-16	-1%	133	6%	20%	20%	-9%	20%	1
	February	-55	-4%	41	2%	0%	0%	0%	0%	1
	March	-46	-4%	24	3%	-10%	40%	5%	-60%	2
	April	-151	-10%	58	6%	20%	60%	-9%	-20%	2
	May	-316	-23%	333	24%	40%	100%	-18%	-20%	5
	June	-222	-28%	-121	-12%	60%	180%	-27%	-60%	5
	July	-93	-30%	0	0%	110%	240%	-50%	-20%	5
	August	-51	-27%	18	14%	130%	340%	-59%	-80%	5
	September	-13	-6%	30	12%	40%	80%	-18%	0%	3
	October	58	16%	74	13%	10%	20%	-5%	0%	2
	November	23	2%	180	12%	10%	20%	-5%	0%	1
	December	-101	-7%	267	19%	20%	20%	-9%	20%	1
Group 2:	N-Day Annual Extremes	(cfs)	%	(cfs)	%	%Diff	Lower	Middle	Upper	5= High 1= Low
	1-Day Min^	4	3%	-42	-49%	-40%	-40%	19%	-40%	3
	3-Day Min	-16	-12%	-33	-43%	-60%	-20%	29%	-100%	4
	7-Day Min	-16	-12%	-28	-36%	-10%	80%	5%	-100%	3
	30-Day Min	-30	-19%	-7	-8%	80%	220%	-38%	-60%	4
	90-Day Min	-30	-15%	-3	-2%	70%	180%	-33%	-40%	4
	1-Day Max^	-848	-10%	-7512	-68%	-70%	-40%	33%	-100%	3
	3-Day Max	-284	-4%	-3772	-49%	-80%	-60%	38%	-100%	3
	7-Day Max	-33	-1%	-357	-8%	-10%	20%	5%	-40%	2
	30-Day Max	17	1%	-95	-4%	-20%	-20%	10%	-20%	1
	90-Day Max	-64	-4%	100	12%	30%	80%	-14%	-20%	2
Group 3:		days	%	days	%	%Diff	Lower	Middle	Upper	5= High 1= Low
	Julian Date of Annual Minimum	-20	-8%	8	19%	73%	220%	-38%	-50%	3
	***Julian Date of Annual Maximum**	1	1%	2	3%	30%	20%	-14%	40%	2
Group 4:		Counts or days per year	%	Counts or days per year	%	%Diff	Lower	Middle	Upper	5= High 1= Low
	Low Pulse Count	-1	-11%	2	43%	18%	20%	-10%	40%	2
	High Pulse Count	1	5%	2	40%	50%	60%	-23%	40%	3
	Low Pulse Duration (days)	9	49%	11	41%	10%	-100%	-5%	120%	4
	High Pulse Duration (days)	-1	-8%	-1	-23%	10%	100%	-5%	-80%	2
Group 5:		cfs or days	%	cfs or days	%	%Diff	Lower	Middle	Upper	5= High 1= Low
	Fall Rate (cfs)	19	12%	2	2%	-20%	-60%	9%	20%	2
	Rise Rate (cfs)	-53	-22%	-22	-12%	40%	140%	-18%	-60%	5
	Fall Count (avg per year)	-27	-12%	-10	-24%	170%	440%	-77%	-100%	4
	Rise Count (avg per year)	-9	-6%	6	32%	40%	160%	-18%	-80%	3
	Fall Count (10% Rule)	-10	-10%	-10	-25%	-29%	0%	14%	-60%	2
	Rise Count (10% Rule)	-8	-11%	0	-1%	-19%	40%	9%	-80%	3

^Values for annual extremes are not well represented as a result of the methods used to generate the natural (without HHD/TPU).

* Annual Maxima is computed on a shift of the julian date (ie. Oct 1 = julian date of 1)
Then the shift is taken out after the statistics (eg. January 1 = julian date of 1).

Table Hydro-Add-3. Summary of With- and Without-projects Flow Conditions Data.

Upper Green River IHA, RVA Statistical Analyses	Generated Natural Flow Conditions (without HHD or TPU Diversion)				Excursions Outside RTV	Measured Flows (with HHD and TPU Diversion)				Excursions Outside RTV
Group 1:	Median (cfs)	RTV Upper (cfs)	RTV Lower (cfs)	RTV (cfs)	(in percent)	Median (cfs)	RTV Upper (cfs)	RTV Lower (cfs)	RTV (cfs)	(in percent)
January	1574	2780	675	2105	31%	1558	2825	587	2238	38%
February	1250	2431	650	1781	31%	1195	2420	597	1823	31%
March	1124	1572	850	722	31%	1078	1516	771	745	28%
April	1456	1969	919	1050	31%	1305	1950	841	1108	38%
May	1389	2263	902	1361	31%	1073	2207	513	1694	44%
June	785	1446	454	993	31%	563	1092	220	872	50%
July	312	617	232	385	31%	219	537	151	385	66%
August	189	286	162	124	31%	138	260	119	141	72%
September	204	402	142	260	31%	192	411	121	290	44%
October	362	773	193	580	31%	420	804	149	654	34%
November	956	1946	474	1472	31%	979	2063	411	1652	34%
December	1446	2217	821	1396	31%	1345	2421	758	1663	38%
Group 2:										
1-Day Min	115	152	68	85	31%	119	141	98	43	19%
3-Day Min	134	174	99	76	31%	119	142	99	43	13%
7-Day Min	136	186	109	77	31%	120	151	102	50	28%
30-Day Min	158	212	130	82	31%	129	183	107	76	56%
90-Day Min	199	289	163	126	31%	170	258	135	123	53%
1-Day Max	8573	16089	5038	11051	31%	7725	9375	5836	3539	9%
3-Day Max	6806	11973	4243	7730	31%	6522	8599	4642	3958	6%
7-Day Max	5102	8017	3403	4613	31%	5069	7437	3181	4256	28%
30-Day Max	2569	4213	1975	2238	31%	2587	4163	2021	2143	25%
90-Day Max	1753	2282	1428	854	31%	1689	2266	1312	954	41%
Group 3:										
Julian Date of Annual Minimum	261	284	240	44.3	34%	241	275	222	53	59%
***Julian Date of Annual Maximum**	99	122	62	60.9	31%	99	124	61	63	41%
Group 4:										
Low Pulse Count	4.5	7.0	3.0	4.0	34%	4.0	7.7	2.0	6	41%
High Pulse Count	10.5	14.0	9.0	5.0	31%	11.0	14.0	7.0	7	47%
Low Pulse Duration	18.0	36.0	10.0	26.0	31%	26.8	52.0	15.4	37	34%
High Pulse Duration	7.8	11.4	5.9	5.6	31%	7.1	9.5	5.2	4	34%
Group 5:										
Fall Rate	158	223	99	124	31%	177	256	130	126	25%
Rise Rate	238	353	171	182	31%	185	297	137	160	44%
Fall Count	215	244	203	41	31%	188	204	173	31	84%
Rise Count	131	138	120	18	31%	123	136	112	24	44%
Fall Count (10% Rule)	91	105	67	38	31%	82	96	67	29	22%
Rise Count(10% Rule)	72	82	53	30	31%	64	77	47	29	25%

* Annual Maxima is computed on a shift of the julian date (ie. Oct 1 = julian date of 1)
Then the shift is taken out after the statistics. Thus anything over 365 means January, February, etc.

An example for quantifying distribution changes for the January monthly mean flow rates is shown below in Figure Hydro-Add-2 and in the text below. The number of annual January monthly mean flow rates that fall outside of the defined range of typical values (the RTV) increases by 20 percent under the with-project scenario. However, both with- and without- projects monthly means are evenly distributed above and below RTV limits, with 50 percent of the extreme values occurring above the 84th percentile threshold and 50 percent of the extreme values occurring below the 16th percentile threshold. Furthermore, the magnitude of the RTV increases 6 percent (see Table Hydro-Add-2, column 4) which constitutes only a mild increase in variability. The Index of Hydrologic Change based on these results is valued at 1, the lowest level. All of this together suggests that HHD and Tacoma Public Utilities (TPU) diversion operations have caused only minor changes to January monthly means. Similar and even less significant are the changes in the February monthly means (see Table Hydro-Add-2)

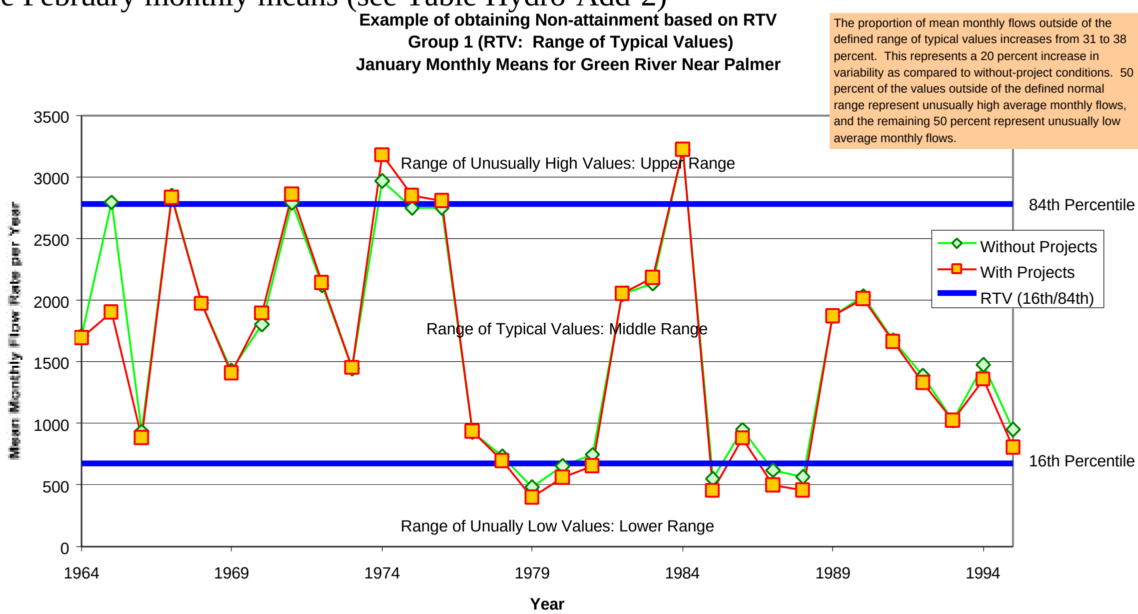


Figure Hydro-Add-2. Example of determining distribution of flows outside the range of typical values for January Monthly Mean flow rates. Note the defined range of typical values is based on the 16th and 84th percentile thresholds of the "without-project" mean flows.

Spring and Summer (March through September)

March shows a 10 percent decrease in the number of unusually high or low mean monthly flows. However, the distribution of the monthly mean flows is much more descriptive. There is a 60 percent decrease in unusually high flows (above the 84th percentile value of 1572 cfs), while there is a 40 percent increase in unusually low flows (below the 16th percentile value of 850 cfs), and a 5 percent increase in typical flows falling between these values. It appears that HHD is reducing the extremes, and shifting the distribution to lower flows. Again, the TPU diversion no doubt plays a role in this net reduction as does the operations of the HHD capturing water summer low flow augmentations. Effects on April monthly means are similar except for a slightly greater shift in the distributions to the lower range of values below the 16th percentile (see Table Hydro-Add-

2). Overall the changes in the early spring hydrology are considered to be rather minor with an Index of Hydrologic Change of 2 for both months.

For the months of May and June, the analysis consistently shows that the river flows more often at "unusually" low levels. The median of the monthly mean flows has decreased by 23 percent and 28 percent respectively as compared to the without-project scenario. For May, the number of data points less than 902 cfs (the 16th percentile threshold for May) increases by nearly a factor of 2 from 16 percent to 31 percent of the time. Similarly, June "low" flows (less than 454 cfs) occur in 38 percent instead of 16 percent of the years (see Table Hydro-Add-2). The magnitude of the shifts in distributions and the reduction in the monthly means results in an Index of Hydrologic Change of 5. This is likely due to the combined effect of Tacoma's direct water withdrawal from the river and of these months historically being the heart of the Corps' spring refill period for Howard Hanson Reservoir, so that much of the melting snowpack and springtime precipitation was being stored for later release during the summertime. Springtime refill has occurred earlier in more recent years, so that these results might differ if the current operating guidelines were fully analyzed in place of the historic record.

The entire flow distribution is dramatically shifted downward in July and August, with median flows decreasing by 27 percent and 30 percent, respectively. For August, this shift results in a median measured flow value of 138 cfs. Consequently, excursions outside the RTV for May through August have increased by factors ranging from 2.1 to 2.3. The distribution of monthly means shifts from the assumed 16 percent above, 16 percent below the RTV range (which occurs for without-project flows) to 3 percent exceedance above and 69 percent exceedance below the RTV. So under the with-projects scenario, 96 percent of the values outside the RTV are in the low distribution band for the month of August. Similarly, the June and July distributions of excursions are 88 percent and 81 percent in the "low" distribution band.
More specifically, simulated "natural" conditions show that 44 percent of the mean monthly July flows occur between 250 and 350 cfs. This distribution shifts downward by 100 cfs, with 47 percent of the flows occurring between 150 and 250 cfs for with-project conditions. Similarly in August, 69 percent of the flows occur between 200 and 300 cfs for simulated without-project conditions. With- project flows for the same time period show 60 percent of the flows are now between 150 and 200 cfs. This shift coincides with typical magnitudes of the TPU diversion, thus suggesting the conclusion that the diversion is responsible for this distribution shift, and that HHD does not successfully augment flows to overcome the diversion impacts. Given the magnitude of these changes the Index of Hydrologic Change is 5.

September flows appear to be moderately influenced by the projects. There is an estimated 40 percent increase in the number of unusually high or low flows. Two-thirds of those unusual flows fall below the low flow threshold of 142 cfs, suggesting that the distribution has shifted toward lower flows (see Table Hydro-Add-2). These moderate shifts result in an Index of Hydrologic Change of 3.

Extreme Lows and Highs

The second section of Tables HydroAdd-2 and 3 demonstrate IHA results for the interannual distributions of annual extremes over a range of durations. The standard IHA approach of focusing simply on the increase in the number of values outside the RTV would suggest that changes to flow extremes resulting from the projects are minor. However, this is deceiving, because it does not account for the potential impact on less frequent events, which may play an important ecological function. Sample medians of the 3-, 7-, 30-, and 90-day minima have decreased by between 12 and 19 percent from the without-projects condition. The 3-day minima, for example, is 134 cfs for without- projects conditions vs. 119 cfs with the projects in place.

The upper tail of the without- projects flow distribution has been consistently and substantially truncated. For example, 47 percent of the 3-day annual minima under "natural" conditions would have been between 80 cfs and 140 cfs. With the combined operational impacts of HHD/TPU, 78 percent of all occurrences are within this range (see Figure Hydro-Add-3. Distribution of Mean 3-Day Annual Minima (1964-1995). Similar changes have occurred to the 7-day minimum flows. Longer duration minima are statistically quite similar between the two samples. In fact, there appears to be a trend with the durations. For short duration minima, the with-project flows have a tight distribution. As the duration increases, the with-projects regime transitions to a distribution that is more similar to without-projects flows but with a shift toward lower overall flow rates. In general, even with the specific low flow augmentation objective of Howard Hanson Dam, it appears that the effects of the TPU diversion were not fully offset by Dam operations. The potential for unusually low short-duration flows during dry years still exists. It appears springtime storage for conservation did not fully make up for the diversion's impacts in these drought years.

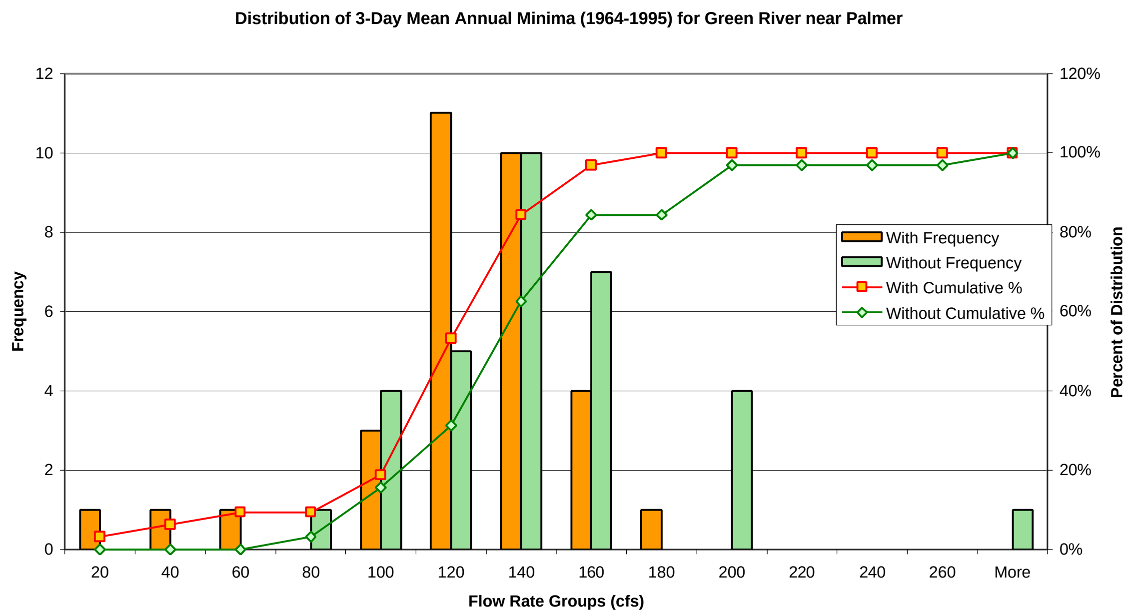


Figure Hydro-Add-3. Distribution of Mean 3-Day Annual Minima (1964-1995) for the Green River near Palmer

The comparison of the distributions of annual maxima for the without-project and with-project scenarios shows far more contrast than the minima. This arises from the obvious impact that HHD has had in suppressing flood discharges and is most evident for the shorter duration maxima. Comparing 3-day maxima, 16 percent of natural (without HHD/TPU) 3-day maxima exceeded 11,000 cfs while there are no incidences of these large flows with HHD and the TPU diversion in place (see Figure Hydro-Add-4 Green River near Palmer 3-Day Annual Maxima from 1964-1995)The difference between the without-project and with-project samples declines quickly as the duration of the maxima increases.

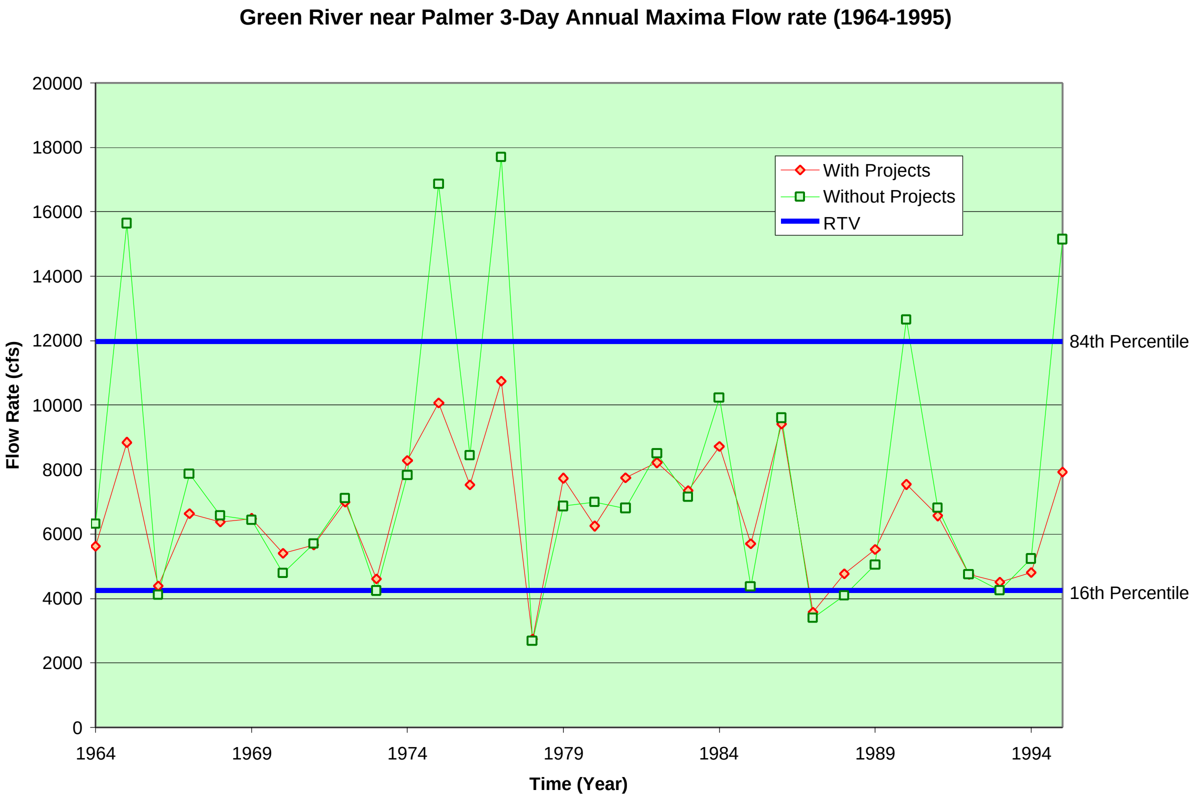


Figure Hydro-Add-4 Green River near Palmer 3-Day Annual Maxima from 1964 to 1995

The Index of Hydrologic Change varies from 1 to 3 for the maxima comparisons, with moderate (level 3) change occurring in the 3-day flows. Given the extreme moderation of short-duration flood flows due to HHD operations, this index may understate the significance of the change in this instance.

Timing of Annual Extremes

The IHA method calls for calculation of statistics based on Julian dates of annual extremes. The Julian date is calculated sequentially from the first day of the calendar year, which takes on a Julian value of 1. For hydrologic regimes where the date of annual extreme values straddles the New Year, the use of Julian dates produces unreasonable statistics. For this reason, this analysis used October 1, the first day of the hydrologic water year, as the first day of the year for computing timing of maxima. The results have then been converted back to calendar dates for discussion purposes. Although the validity of the magnitude of the 1-day annual maxima and minima is uncertain, the timing of the 3-day and 1-day annual maxima and minima are the same. Hence, discussions in this section will refer to annual extremes of unspecified duration.

Under without-projects conditions, the annual minimum flow typically occurred during the third week of September (the median value). In approximately 2 out of 3 years, the minimum daily flow occurred in a 44-day period between August 28 and October 11. In the measured (with-projects) flow sample, the median date shifts earlier in the year by about 3 weeks and the date range for 2 out of 3 years lengthens to about 53 days--starting on about August 10 and ending October 2. In the with-projects flow regime, the minimum flow is typically earlier, but also more variable in its timing. The driving factor behind this shift in the flow regime is unclear.

As discussed earlier, three-day maximum flows have been greatly reduced by HHD operations. These lower maximum flows tend to occur on the same date under with- and without-projects conditions with a median date of January 2. The variability of the annual maximum flows has increased only slightly and is considered to be negligible. Two-thirds of annual maximum daily flows would have occurred between December 1 and January 30 without the projects in place. With the projects, two-thirds occur between November 30 and February 1. These differences in timing are very small in comparison to the change in magnitude of annual maximum daily flows discussed earlier.

Frequency and Duration of Low and High Flow Pulses

In this section a low flow pulse is defined as a decline in daily discharge below the 75 percent exceedance level and conversely, a high flow pulse is a rise above the 25 percent exceedance level. For the Green River near Palmer, the daily mean flow thresholds at the respective exceedance levels are approximately 302 and 1292 cfs. This category includes 4 annual parameters: the number of high pulses, the number of low pulses, and the mean duration of each type of pulse. Of these four statistics, the low pulse durations in particular appear to have changed substantially, with an increase of 49 percent in the median duration of flows below the low flow threshold compared with natural (without-projects) conditions. High pulse counts and durations are not well represented using the 25 percent exceedance level, which is simply set too low to have much ecological relevance. To better elucidate the high pulse counts and durations, a 1 percent exceedance level (5925 cfs) could be used as a better descriptor.

Low Pulse Counts, Low Pulse Durations, and Total Annual Low Flow Days

The average number of low pulses under the with-project scenario decreased from around 4.5 per year to 4.0 per year as compared to the without-project scenario. In this case, the RVA analysis may not be completely suitable. The annual data are integer values within too narrow a range to be considered approximately continuous. Given the change in median values from 4.5 to 4.0, it would appear that the annual incidence of low flow pulses has not decreased significantly. However, low flow durations do change substantially. On average the low flow pulse increases in duration by 9 days. This is a 49 percent increase over without-project conditions. This again is likely an effect of the TPU flow diversion not being completely overcome by Howard Hanson Dam flow augmentation.

Although it is not included on the standard IHA “report card”, another useful statistical parameter may be the total number of annual days of low flows, which is simply the product of the average annual low pulse count and the average low pulse duration. On average, there are 49 percent more days per year with flows of less than 302 cfs, the low flow pulse threshold. Additionally, a comparison of the cumulative distributions for these two data sets shows that the 84 percent exceedance value for the number of annual low flow days (107 days per year) has become a 97 percent exceedance for the HHD/TPU sample. Furthermore, the 16 percent exceedance under without-projects flows (40.4 days) increases to 38 percent exceedance. In other words, there are over twice as many years where low flows persist for more than 40.4 days.

High Pulse Counts, High Pulse Durations, and Total Annual High Flow Days

Neither comparison of medians nor comparison of distribution ranges suggests much change in the number of annual flow excursions above 1292 cfs (the 25 percent exceedance daily mean under without-project conditions). This recommended IHA threshold does not appear to have much ecological relevance in that most of the ecological functions associated with high flows—scouring of bed materials, floodplain recharge, creation of new channel forms, etc.—are associated with flood events rather than routine moderate high flows. Thus a more stringent high flow threshold might be more instructive. As for high flow pulse durations, the median and magnitude of the RTV have either stayed the same or decreased with HHD/TPU in place (see Table Hydro-Add-2, Group 4, column 4), but not substantially. The 16 percent non-exceedance threshold for average annual high pulse duration has shifted from 11.4 days to 9.5 days.

Since this parameter is described as a “high” flow threshold, one might be tempted to interpret this hydrologic change as resulting from the flood control operations at HHD. However, 1292 cfs is much smaller than a flood condition for the Green River. In fact, when using a pulse rate defined as the 1 percent exceedance level (5925 cfs), the influence of HHD operations clearly result in an increase in high flow pulse durations (over 39 percent) despite the pulse counts remaining about the same (see Table Hydro-Add-4 below). The conclusion here is that Green River flood peaks are now substantially reduced, but they persist for much longer periods of time.

The reader should note that the mean is used instead of the median for average evaluation. The median would not represent correctly the observed differences between without- and with-projects conditions given the small number of excursions.

TABLE Hydro-Add-4. Comparison of High Pulse Counts and Durations Using the One Percent Exceedance Flow Threshold (5925 cfs).

High Pulse Rate defined by 1 percent exceedance level (5925 cfs)								
	Without Projects High Pulse		With Projects High Pulse		Difference relative to without Projects			
	Durations	Counts	Durations	Counts	Durations	Counts	Durations	Counts
min	0	0	0	0	0	0	N/A	N/A
max	5	7	7	7	2	0	40%	0%
mean	1.6	1.7	2.3	1.6	0.6	-0.1	39%	-4%

IHA Rates and Frequencies of Change

Group 5 includes four annual statistics that measure the average number of rises and falls per year, and the magnitude of those rises and falls. Richter, et. al. (1996), did not provide any guidance on applying a threshold to determine which individual flow rises or falls are worth counting. Therefore, the detection of a rise or fall is only dependent on the precision with which the daily flow data are reported, in this case 1.0 cfs. This means that a one-day "blip" with a 1.0-cfs incremental increase in flow followed by a corresponding 1.0-cfs decrease is counted as a rise just as a similar event involving a 1,000 cfs change is counted. This results in the analysis being a simple accounting of how often river flows are in a rising versus a falling hydrograph.

With this caveat in mind, the following are the results of the IHA report card (Tables Hydro-Add-2 & 3).

Fall Rate (the average daily decrease in flow for "falls" or declining flow days)

With and without HHD/TPU influence, the basic statistics appear quite similar, yet there appears to be a distinct loss of variability in the with-project statistics. By IHA standards, there has been a mild change based on the IHA Range of Typical Values criteria. However, there has been some loss of variability with a 60 percent decrease in values above the 84th percentile, a 9 percent increase in the number of values within the RTV, an overall decrease of 20 percent in variability, and an Index of Hydrologic Change of 2.

Rise Rate (the average daily increase in flow for "rises" or rising flow days)

There appears to be a significant reduction in the rate at which Green River flows tend to rise. Under without- projects conditions, the median rise in flows per day during a rising hydrograph period is 238 cfs. With the projects in place, this has been reduced to 185 cfs.

The overall distribution shifts downward as well. The number of values falling outside the Range of Typical Values for with-projects conditions is excessive, about 40 percent more than would be expected under without-projects flow conditions, with 2.4 times as many values falling below the 16th percentile. Comparisons of the cumulative distributions basically corroborate the pattern shown by these statistics--many years exhibit much smaller average rates of rise than would have occurred without the projects in place. This suggests that the Green River has lost a certain amount of overall dynamism, a finding that would be consistent with controlled floods with the projects in place. The Index of Hydrologic Change evaluates this change to be among the most significant with an index level of 5. It is unclear what role this change plays in the factors of decline analysis for salmonid production.

Fall Count--This metric counts every 1.0 cfs or larger daily reduction in flow. The median annual fall count appears to have fallen moderately. The number of values outside of the RTV is 170 percent higher than under the without-projects regime. However, the lack of precision in the definition of this statistic (any fall or rise gets counted no matter how small) and the uncertainty of its ecological importance make the value of additional comparison and analysis questionable at this time.

Rise Count- As discussed above, the statistic is too poorly defined to make meaningful comparisons. These counts might have more meaning if a threshold were utilized. For example, rises or falls could be required to involve a change of at least 10 percent in the mean daily flow relative to the previous day in order to be counted. This requirement has been applied and analyzed as follows.

When the fall and rise count statistics are computed using a requirement of a 10 percent change in the mean daily flow relative to the previous day, the with-projects regime exhibits moderate decreases in the median number of annual falls and rises of approximately 10 percent and 11 percent, respectively. The number of falls per year decreases from 91 to 82, while the number of rises decreases from 72 to 64 per year. The counts show an overall shift downward in the number of flow changes greater than 10 percent for the statistics with the HHD/TPU projects as compared to "natural" (without projects) conditions.

The proportion of counts outside the Range of Typical Values decreases by 29 percent and 19 percent, respectively, suggesting that the number of these events per year becomes overall, less variable with the projects in place. The distribution of the counts shifts from approximately 50 percent each above and below the RTV to an 80 percent decrease in the number of counts above the 84th percentile and an increase of 9 percent in the RTV and a 40 percent increase in counts below the 16th percentile. Because of the weighting applied to the median percent change and the percent change in the RTV, the Index of Hydrologic Change is 3. These shifts again seem to indicate an overall decrease in the dynamism of the river's flow regime.

This 10 percent rule or a similar modification, perhaps applied over the springtime data set only, appears promising in evaluation of the adequacy of freshets.

SUMMARY OF HYDROLOGIC ALTERATIONS

The most notable trend between flow conditions with and without the Howard Hanson Dam and Tacoma Public Utilities projects is the overall decrease in most median flow values. Related to this finding is the overall downward shift in flow distributions and in the percentage of unusually low values compared to the without-projects conditions. Along with this shift downward, interannual variability of monthly means tends to increase, largely because lower mean values shift down by a greater amount than higher mean values.

In contrast, the variability of many of the other parameters—minima, maxima, and fall and rise rates and counts—tends to decrease. In addition, the median rate at which river flows rise per day decreases. Taken together, this suggests an overall loss in river flow dynamism. River flows change more slowly on a day to day basis than under “natural” (without- projects) conditions, especially during rising periods, and both flood and low flows are reduced and highly moderated.

For large magnitude events (flood flows), the effects of Howard Hanson Dam are quite clear. One-day and 3-day annual maxima medians decrease substantially, as does the upper end of the distribution. Without-projects daily mean flows range from 70 to 29,000 cfs with 16 percent of annual 3-day maxima exceeding 11,000 cfs. Howard Hanson Dam operations significantly truncate the upper end of this distribution, however, no flows above 10,700 cfs have been measured at Palmer with the projects in place.

The effects of the TPU diversion are less obvious than those attributable to operation of Howard Hanson Dam. The influences of the TPU diversion appear to be noticeable only during low flow periods when the amount of water being diverted comprises a significant percentage of the river flow. Furthermore, it has not been identified whether other factors may play a part in any deviation from natural conditions resulting from the diversion. Without examining individual events and TPU operational practices, it is difficult to determine whether and to what degree the diversion influences the hydrologic regime except for the fact that reductions in monthly means are clearly at least partially attributable to the diversion. It is also clear that HHD flow augmentation does not fully overcome the flow reduction effects of the diversion during extreme low flow periods.

Table Hydro-Add-5 summarizes the results of the comparisons for each individual IHA parameter.

Ecological Implications

The areas of hydrologic change due to operation of the projects appear to have clear implications for Green River salmonid ecology. Some of these implications are highlighted below:

1. Reduction in annual minimum and summertime low flows, and increase in duration of flows below 302 cfs low flow threshold. This hydrologic impact clearly reduces spatial habitat for rearing, and reduces water depth in pools, glides, and riffles. Reduced water depth over riffles increases the difficulty and energy expenditure of upstream migrating adult salmon, particularly chinook which are migrating during the low flow period. Reduced depths also reduce the quality and quantity of pool habitat used by holding adults, particularly chinook. Reduced pool depth increases the vulnerability of juvenile salmon to some predators. Reduced flows typically reduce water velocity and thus the speed of juvenile salmon outmigration, particularly for chinook and coho. Survival of outmigrating juvenile coho increases with flows and it is thought the same applies to chinook. Low mainstem flows may also be reducing upstream adult and overall juvenile movement in the river and into tributaries and side channels, and may be resulting in a redistribution of chinook redds towards the middle of the river, where flows are deeper and more subject to scour during high flows. Chinook adult migration in particular occurs during the late summer and early fall when these effects are most pronounced. However, reduced flow volumes affect the entire suite of salmonid species. The reduction in low

flows likely also plays a role in the high temperatures the Green River experiences during this time period.

2. Timing of annual minimum flow. The earlier minimum flows may also be affecting the timing of upstream adult migration, and may be contributing to warmer, more stressful instream conditions. The period of earlier minimum flows may correspond to the period of time when many chinook are shifting from upstream migration and holding to spawning.

3. Reduction in annual maxima (flood peaks). The Green River likely has less ability to create new side channel habitat, maintain existing side channels, and recharge its floodplain. In addition, river margin habitats such as gravel bars are less dynamic environments and are stabilizing, with vegetation recolonizing gravel bars throughout the upper portions of the Middle Green River from Flaming Geyser to Whitney Bridge. Without recruitment of gravel above HHD, any flow rates above the threshold of incipient bedload motion will erode away existing gravel bars resulting in a net loss of gravel bar habitat in this same reach. Reduction of flood peaks may also reduce the recruitment of wood from the floodplain and the stream margins.

4. Changes in durations of moderate flood flows. The picture here is somewhat unclear as durations of flows above 1292 cfs have decreased slightly due to the projects, while durations above 5925 cfs have increased. River bed scour is thought to be initiated at 1000 cfs in the Palmer reach, and at 2000 cfs downstream of Flaming Geyser. However, a detailed sediment budget to integrate bed movement information with a flow duration curve has not been performed at this time.

Data Gaps

The results of the analysis suggest several data gaps where additional research into flow records and/or records of operations may improve these conclusions. Two of these are listed below:

- Howard Hanson Dam operations--The analysis of managed conditions is wholly based on the measured flows at Palmer over the period of record, even though Howard Hanson Dam operations have changed during that time period. In particular, changes in spring refill timing and flood ramping rates may have an impact on downstream hydrologic conditions. The model could be revised to clearly define HHD operating guidelines and simulate managed conditions over the entire time period as if current operations had prevailed.

- TPU flow diversion records and protocols--Review of diversion records would improve the evaluation of diversion impacts during extreme low flow periods by isolating the effects of the diversion from HHD flow augmentation operations. From a comparison of mean monthly flows for with- and without-projects conditions, it is clear that the entire 113 cfs diversion right was not always implemented.

Possible Improvements to the IHA/ RVA Methodology as Applied to the Green River

There are several areas where the methodology itself could perhaps be improved, at least for application in the Green River. Since the primary goal of this addendum is to present a methodology for describing hydrologic changes in terms that may be useful in determining ecological factors of decline, it is worth noting several aspects of the analysis that might be improved through modification.

Additionally, the specific flow characteristics chosen for the analysis may not be those with the greatest ecological relevance for the Green River. Again, characteristics were chosen based on the method as described by Richter, et. al. They are statistically based and in aggregate comprehensively describe the flow regime. However, modification of individual parameters might improve the relevance for analyzing effects on Green River ecology.

For any changes to the method to be made, they should not only improve its ecological usefulness, but also remain valid and defensible from a hydrologic and statistical point of view. Several possible modifications are listed below:

- As mentioned earlier in the report, the analysis may not accurately model low and high flow extremes. In practice, the 1- and 3-day maxima and minima results are the most suspect. This is due to the smoothing factor used in the simulation of without-project conditions. Improvements to the methodology should focus on evaluating the importance of this error, and on reducing it if necessary.

- The Richter method also recommends choosing the 25th and 75th percentiles for high and low flow duration analysis (i.e., the computed mean duration of high flow pulses is based on all pulses above the 25 percent exceedance level in a given year). However, any flow threshold could be chosen for this analysis, including thresholds of known importance for Green River ecology. Examples might include flow thresholds known to inundate side channel connections, maximize spawning area, mobilize bed sediments, or create significant floodplain recharge. It may be worth increasing the high flow pulse rate threshold to some value or values of common importance to channel morphology and biological conditions. Note that the 25 percent exceedance pulse rate is either very near or below the mean monthly flows during the wintertime, thus providing no further insight into hydrologic alteration. The 1 percent exceedance rate used as a supplement to the original IHA suite of parameters was not *specifically* selected for its relevance in evaluating factors of decline, but clearly provides more descriptive power by focusing on values closer to the upper end of the flow range with the potential to have geomorphic importance.

- In the high and low pulse count analysis, there is no difference in the relevance of a 1 cfs and a 1,000 cfs daily fluctuation. Both trigger one “pulse count.” Further analysis using some threshold of “significant” change relative to the mean daily flow rate should be considered. The “10 percent rule” used as a supplement to the IHA method seems to improve the usefulness of this parameter.

- The mean monthly flow computations may not be a fine enough resolution to fully examine impacts on Green River salmonid life histories. Other options for consideration include comparison of two-week means, or of “rolling” or moving four-week means in which each successive overlapping four-week period is used for comparison (e.g., four week periods might begin on January 1, January 8, January 15, etc.).

- Consideration should be given to modifying the definition of the Range of Variability, currently set at +/- one standard deviation from the mean, or at the 16th and 84th percentiles. These bounds for the range are somewhat arbitrary and have no clear hydrologic significance. The non-parametric analysis appears to provide better results for most flow characteristics; under this approach, a range of flow quantiles could be used or cumulative distributions could be examined in a more rigorous way.

- Consideration should be given to improving the analysis of seasonal impacts of flow alteration. For example, relative low flows might be important for different reasons in the winter as well as the summer. Thus, a low flow analysis specific to the winter/ spring time period may be useful. Relative high flow pulses could also be important within a season, such as spring freshets. The rates of change used to define a “pulse” may require further work, and again the most useful pulse definition may differ by season (e.g., 10 cfs/ day in the summer; 100 cfs/ day in the winter).

- The concept of reducing this analysis to a simple metric such as the Index of Hydrologic Change should be explored further. This idea, which was developed specifically for this addendum, appears to have promise for evaluating the significance of the various aspects of flow change. In its current rendition, however, it may not fully account for certain types of impacts. For example, the 3-day annual maxima index value is 3, which may understate the impacts of flood control on annual peaks.

- The use of statistical validation methods and application of confidence limits should be considered.

LIST OF TABLES

Table Hydro-ES1. Summary of “Natural Flow Analysis” Findings.

Table Hydro -1. Summary of average daily flow in the North Fork Green River, and expected well demand from the North Fork well field (Source: Tacoma 1999).

Table Hydro -2: General ramping guidelines followed by the Army Corps of Engineers for operation of Howard Hanson Dam.

Table Hydro -3: Estimated natural and regulated seven-day low flow and annual minimum flow for the period of 1964 to 1996, compared to the actual flow at the Auburn and Palmer USGS gages on the Green River, Washington.

Table Hydro -4: Instream Flow Requirements at the USGS gage at Auburn (USGS # 12113000) and Palmer (USGS # 12106700) under Ecology’s Instream Resource Protection Program. These requirements may be modified during critical drought years (<1 in 10 low-flow frequency) as specified in WAC 173-509.

Table Hydro -5. Modeled peak flow increases and extent of impervious area in small tributaries to the Green River, Lower Green Subbasin (RM 6.5 to RM 33)

Table Hydro-Add-1. IHA flow characteristics and their ecological relevance

Table Hydro-Add-2. Summary of Changes in With-projects Flow Conditions Data Relative to Without- Projects Conditions

Table Hydro-Add-3. Summary of With- and Without-projects Flow Conditions Data

Table Hydro-Add-4. Comparison of High Pulse Counts and Durations Using the 1 percent Exceedance Flow Threshold (5925 cfs)

Table Hydro-Add-5 Summary Comparison of without HHD/TPU Projects and with Projects

LIST OF FIGURES

Figure Hydro -1 Factors of Decline Study sub-watersheds

Figure Hydro -2. Average monthly flows at USGS Gage 12113000 at Auburn, before and after construction of Howard Hanson Dam.

Figure Hydro -3. Average monthly flows at USGS gage 12106500 near Palmer before construction of Howard Hanson Dam and at USGS gage 12106700 after construction of Howard Hanson Dam. Gages were installed at slightly different locations, but had similar drainage areas (230 and 231 sq. mi. respectively)

Figure Hydro -4. Green River Watershed surface water rights: primary purpose of use as a percentage of total allocated, out of a total allocated quantity of 195.2 cfs (Culhane 1995; Tacoma Water 1999).

Figure Hydro -5. Annual instaneous flows at USGS gage 12113000, Green River near Auburn, 1937 to 1994.

Figure Hydro -6. Flood frequency relationships for USGS gage 12113000 Green River near Auburn,prior to and after construction of Howard Hanson Dam.

Figure Hydro -7. Daily flow duration curves, USGS gage 12113000 Green River near Auburn, prior to and after construction of Howard Hanson Dam.

Figure Hydro -8. Example of springtime flow reductions resulting from refill of the Howard Hanson Dam conservation pool in 1994.

Figure Hydro -9. Average 7-day low flows in the Green River near Auburn (USGS gage 12113000) before and after construction of Howard Hanson Dam.

Figure Hydro -10. Configuration of the Duwamish drainage prior to 1900 and after 1916 (Source: Dunne and Dietrich 1978).

Figure Hydro -11. Average daily flows by month for Big Soos Creek (USGS gage 12112600) and Newaukum Creek (USGS gage 12108500).

Figure Hydro -12. Average 7 day low flows in Soos and Newaukum Creeks from 1953-1993.

Figure Hydro-Add-1. Example for Identifying Index of Hydrologic Change

Figure Hydro-Add-2. Example of determining distribution of flows outside the range of typical values for January Monthly Mean flow rates.

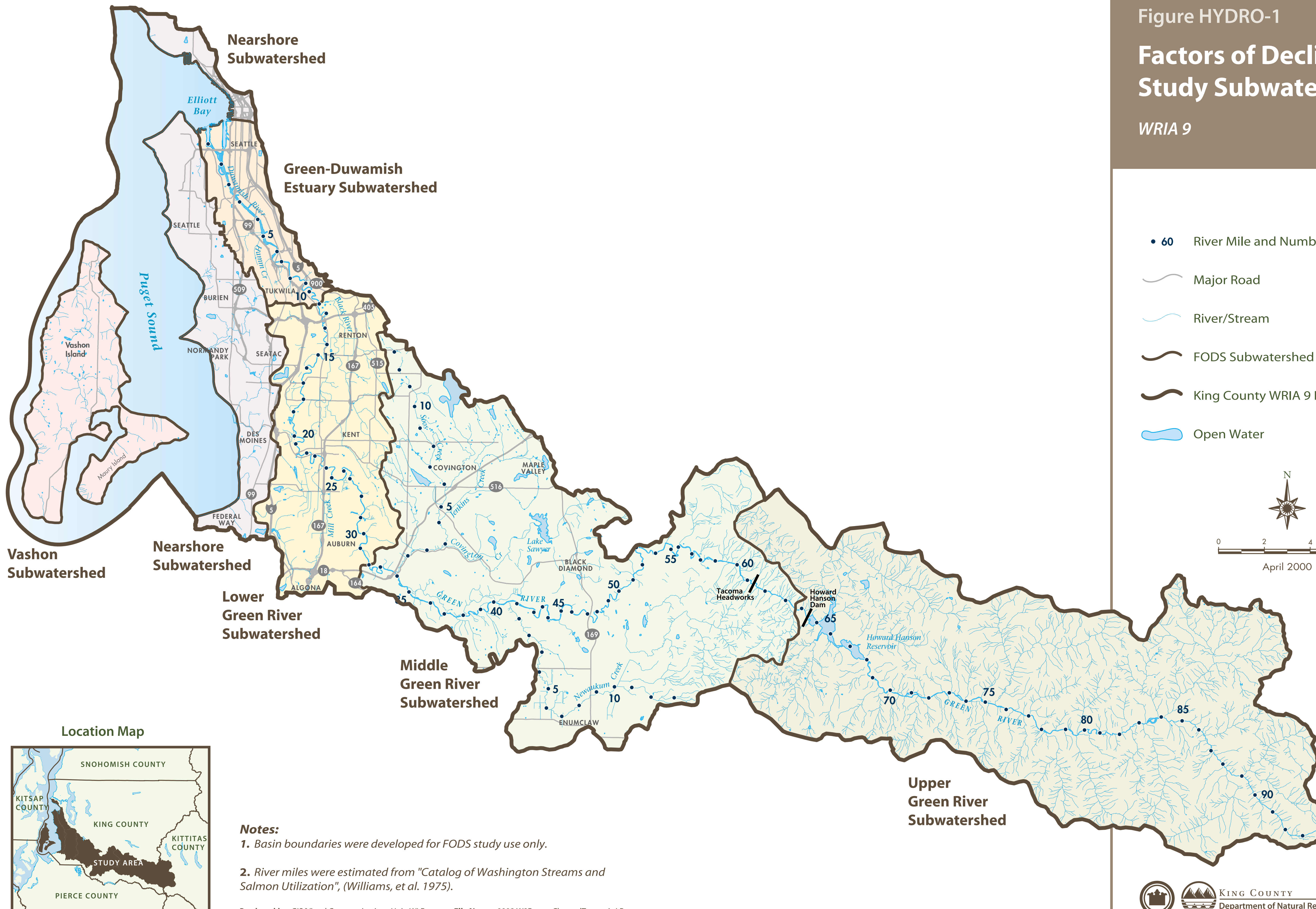
Figure Hydro-Add-3. Distribution of Mean 3-Day Annual Minima (1964-1995) for the Green River near Palmer

Figure Hydro-Add-4 Green River near Palmer 3-Day Annual Maxima from 1964 to 1995

Figure HYDRO-1

Factors of Decline Study Subwatersheds

WRIA 9



• 60 River Mile and Number

Major Road

River/Stream

FODS Subwatershed Boundary

King County WRIA 9 Boundary

Open Water

N

0 2 4 6 Miles

April 2000

Notes:

1. *Basin boundaries were developed for FODS study use only.*

2. *River miles were estimated from "Catalog of Washington Streams and Salmon Utilization", (Williams, et al. 1975).*

Produced by: GIS/Visual Communications Unit, WLR **File Name:** 0008 W9Recon-ChannelTypes.ai LP

King County
Department of Natural Resources

Figure Hydro-2. Average monthly flows at USGS gage 12106500 near Palmer before construction of Howard Hanson Dam, and at USGS gage 12106700 near Palmer after construction of Howard Hanson Dam. Gages were installed at slightly different locations, but had similar drainage areas (230 and 231 sq. mi, respectively).

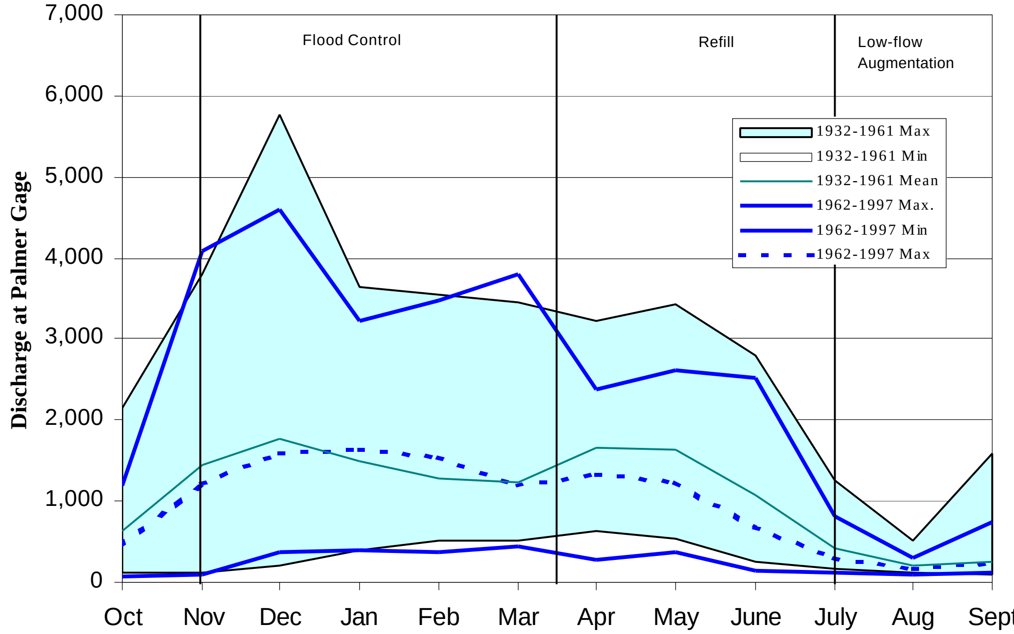


Figure Hydro-3. Average monthly flows at USGS Gage 12113000 at Auburn, before and after construction of Howard Hanson Dam.

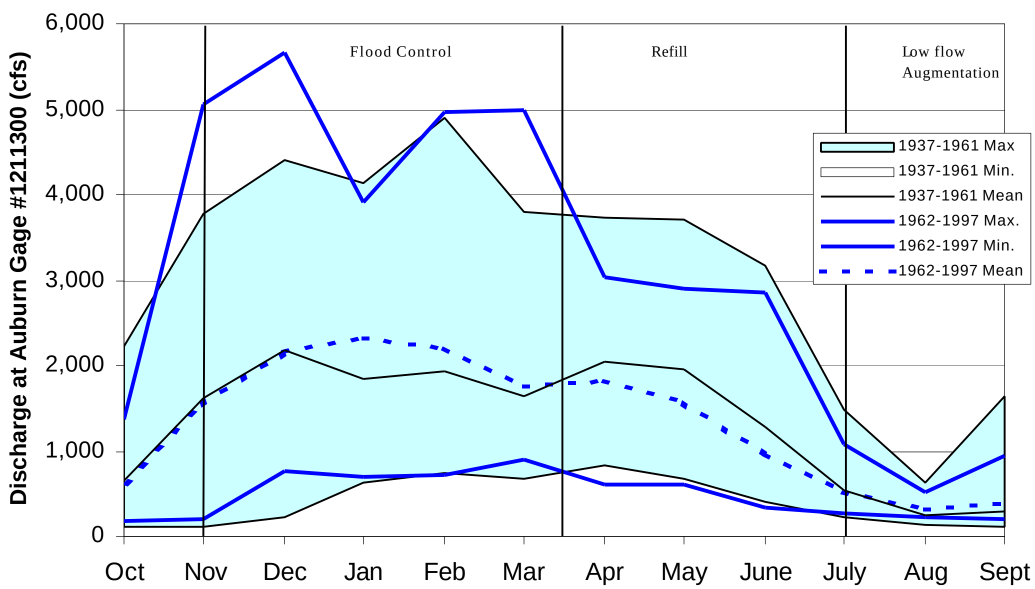


Figure Hydro-4. Green River Watershed surface water rights: primary purpose of use as a percentage of total allocated, out of a total allocated quantity of 195.2 cfs (Culhane 1995; Tacoma Water 1999).

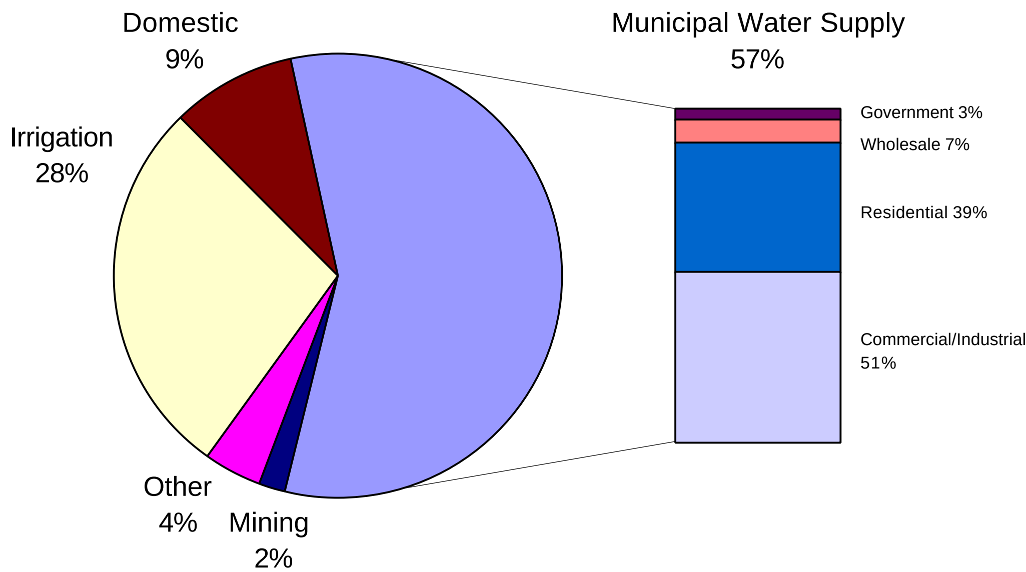


Figure HYDRO-5. Annual instaneous flows at USGS gage 12113000, Green River near Auburn, 1937 to 1994.

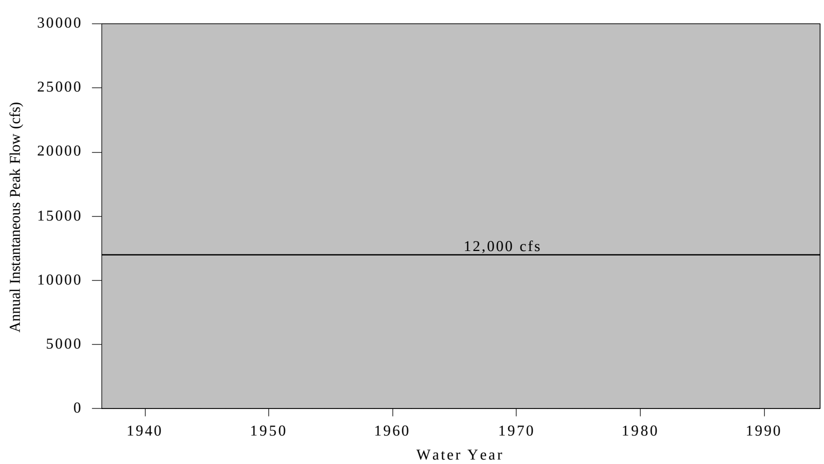


Figure HYDRO-5. Annual instantaneous peak flows at USGS Gage 12113000, Green River near Auburn, 1937 to 1994.

Figure HYDRO-6. Flood frequency relationships for USGS gage 12113000 Green River near Auburn, prior to and after construction of Howard Hanson Dam.

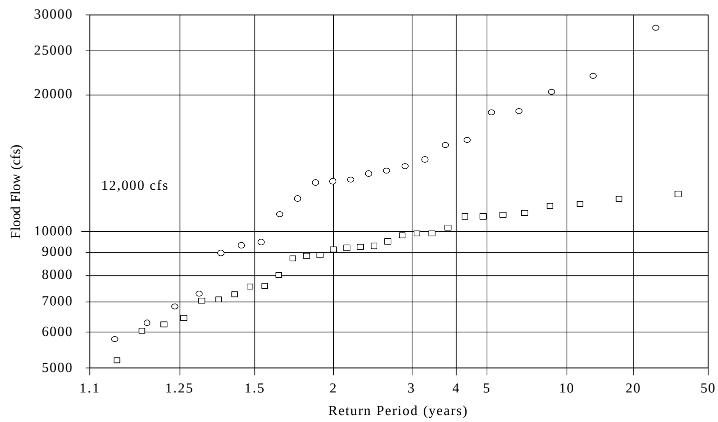


Figure 5-6a. Flood-frequency relationships for USGS Gage No. 12113000 Green River near Auburn, Washington, prior to and after construction of Howard A. Hanson Dam

Figure HYDRO-7. Daily flow duration curves, USGS gage 12113000 Green River near Auburn, prior to and after construction of Howard Hanson Dam.

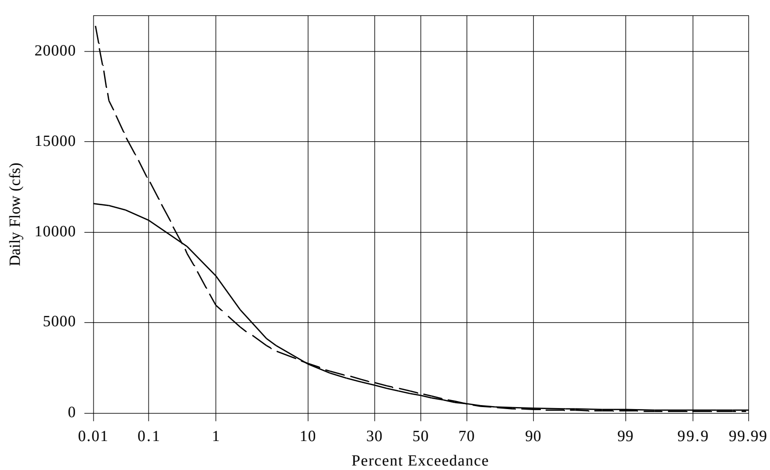


Figure 5-6b. Daily flow duration curves, USGS Gage 12113000, Green River near Auburn, Washington, prior to and after construction of Howard A. Hanson Dam.

Figure Hydro-8. Example of springtime flow reductions resulting from refill of the Howard Hanson Dam conservation pool in 1994.

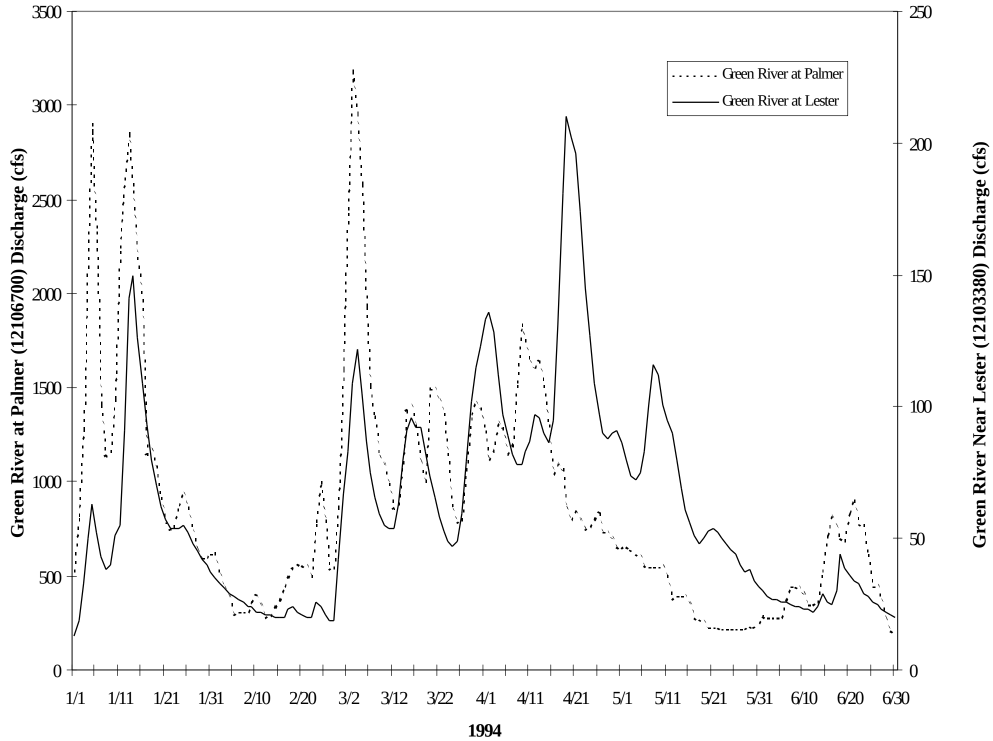


Figure Hydro-9. Average 7-day low flows in the Green River near Auburn (USGS gage 12113000) before and after construction of Howard Hanson Dam.

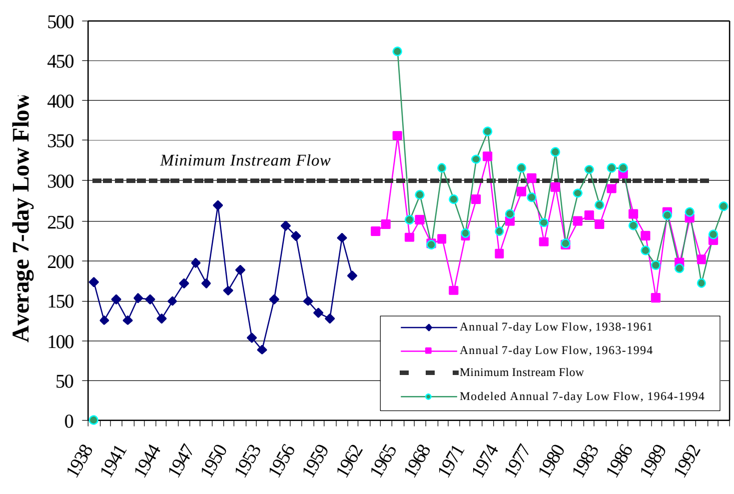


Figure Hydro-10. Configuration of the Duwamish drainage prior to 1900 and after 1916 (Source: Dunne and Dietrich 1978).

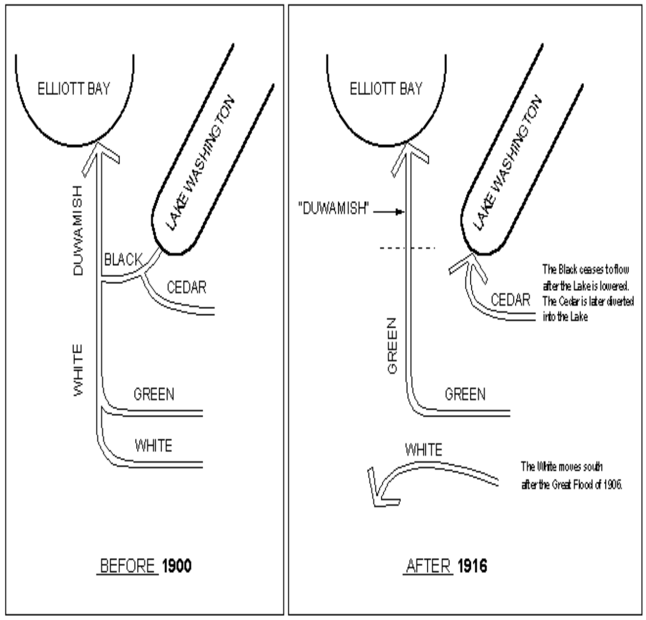


Figure Hydro-11. Average daily flows by month for Big Soos Creek (USGS gage 12112600) and Newaukum Creek (USGS gage 12108500).

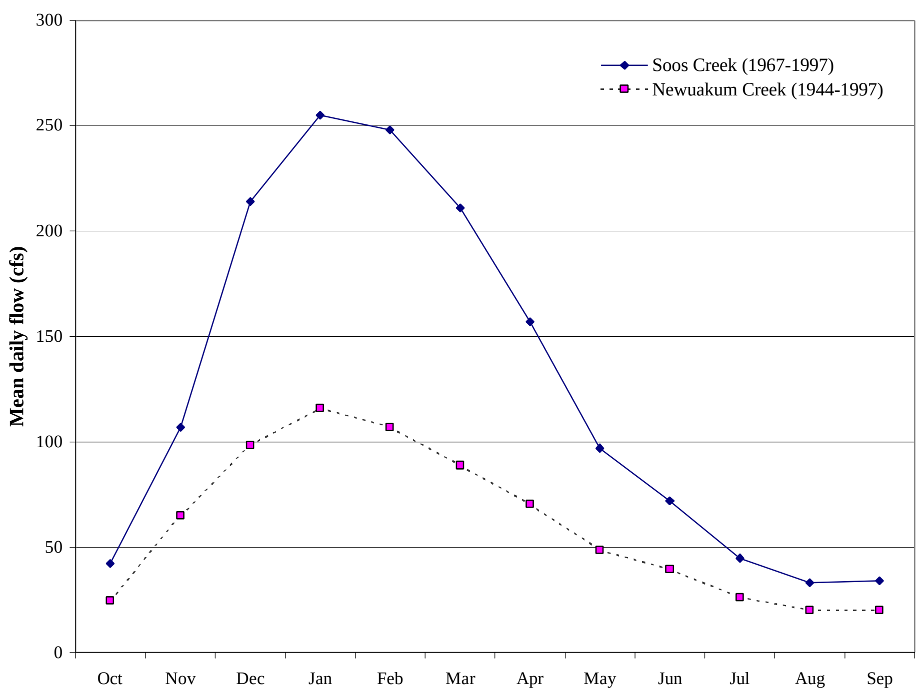


Figure HYDRO-12. Average 7 day low flows in Soos and Newaukum Creeks from 1953-1993.

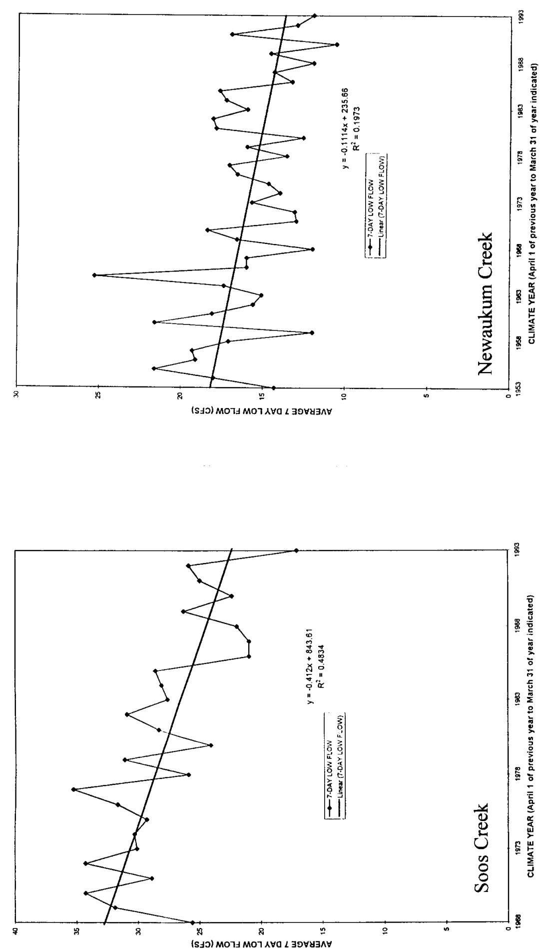


Figure HYDRO-12. Average 7-day low flows in Soos Creek (USGS gage 12112600) and Newaukum Creek (USGS gage 12108500) over the period from 1953 to 1993 (Source: Culhane et al. 1996).

Table Hydro-5
Summary Comparison of without HHD/TPU Projects and with Projects

IHA\RVA Groups	Index of Hydrologic Change	Results of median and RTV (Range of Typical Values) distribution analysis	Comments
Group 1: Monthly Means	5=High 1=Low		
January	**1**	**A 1% decrease in median, and a 133 cfs (6%) increase in magnitude of the RTV. As a result, there is a 20% increase in monthly means outside the Range of Typical Values as defined by the 16th and 84th percentiles relative to without-projects. This increase of unusually high and low monthly means is equally distributed above and below the RTV.**	**Given an index of change of 1, there are no significant changes overall with the exception that outliers are reduced. HHD Operations are reducing magnitude of storm events. Although a 20% increase in the number of monthly means outside the RTV has been identified, these excursions are only slightly greater than under without-projects conditions.**
February	**1**	**A 4% decrease in median, 2% increase in variance as represented in the increase in the magnitude of the RTV. Zero percent increases/decreases in all other statistics.**	**This is the month that is most like the without project conditions. HHD and TPU operations appear to be causing only the slightest of hydrologic changes. Hence, the Index Level of 1. If there was a zero index this month would be ranked as such.**
March	**2**	**A 4% decrease in median of the monthly means, 3% increase in magnitude of the RTV. Overall a 10% increase in the number of monthly means within the RTV.**	**No significance in median flow changes. However, the 10% increase in the RTV is a net result of 3 monthly means shifting from the upper range into the RTV range, and 2 monthly means from the RTV range shifting to the lower range below the 16th percentile. Hence, the net effect is minimal as the shifts in distributions are moderate, yet offsetting for the most part. Because of the distribution shifts, the index level of hydrologic change is listed as a 2.**
April	**2**	**A 10% decrease in the median, 6% increase in in the magnitude of the RTV. Again, only a slight increase in excursions outside the RTV. However, the excursions are a result of the shift in distribution with a 20% decrease in the upper range, and a 9% decrease from the RTV, resulting in a net 60% increase of monthly means in the lower range relative to the without-projects condition.**	**Not much in significance of change, only the shift in distribution to lower flow levels. It is difficult to distinguish the degree to which impacts are attributable to HHD vs. TPU operations. Howevera combination of the TPU diversion and HHD spring refill operations are likely the cause.**
May	**5**	**A 23% decrease in the median with a 24% increase in the**	**The distribution of excursions outside the RTV is 1/3**

Table Hydro-5
Summary Comparison of without HHD/TPU Projects and with Projects

IHA\RVA Groups	Index of Hydrologic Change	Results of median and RTV (Range of Typical Values) distribution analysis	Comments
		magnitude of RTV. There is a 40% increase in excursions outside the RTV as a result of the number of means in the lower range (below the 16th percentile) doubling.	**above, 2/3 below RTV thresholds. Because of the doubling of the unusually low flows in conjunction with the overall reduction in the median, the index of change equates to a 5. Most like the result of HHD operations filling reservoir for low flow augmentation and TPU diversion.**
June	**5**	**A 28% decrease in the median flow. Almost all excursions are below the RTV. The overall variation in monthly means is reduced by 12%, based on the magnitude of the RTV.**	**50% of the flows are outside the RTV limits (60% increase over without projects). Over 88% of these are within the low flow distribution band. Most likely a result of inadequate flow augmentation for the TPU diversion.**
July	**5**	**A 30% decrease in median. Excursions of the RTV slightly more than double to 66%. Again almost all the excursions are a result of the 2.4 times increase in low monthly mean flows (ie. Below the 16th percentile). Monthly means in the RTV are reduced by half. And a modest 20% decrease in the higher monthly mean flows.**	**80% of excursions of the RTV are on the low flow side, more than doubling the frequency. Overall distribution remains similar to without project conditions. This is the second most severe month of extreme low flow events. Again this is likely a result of inadequate flow augmentation for the TPU diversion.**
August	**5**	**27% decrease in the median flow. Variability is only 14% above without project conditions. Similar to July means, August mean low flow excursions increase by a factor greater than 3.**	**Flows are at their lowest; as a result variability is low. 72% of the flows fall outside the RTV with most of them (95%) below low flow limits. Again this is likely a result of inadequate flow augmentation for the TPU diversion.**
September	**3**	**A 6% decrease in the median, with a slight increase (12%) in variability over without project conditions. RTV excursions remain at 40% above without project conditions. All exceedances are below the 16th percentile threshold.**	**Frequency of the monthly means above the 84th percentile remain the same. As a result, this suggests that the operations of HHD are unable to fully compensate for TPU's diversion. Interestingly, although September is commonly considered a critical month for the flow augmentation strategy (as the conservation pool is running out), this analysis suggests flow augmentation has been more**

IHA\RVA Groups	Index of Hydrologic Change	Results of median and RTV (Range of Typical Values) distribution analysis	Comments
			successful here than in July and August.
October	**2**	**A 16% increase in the median flows. Variability has similar increase to September (13% increase). Values falling outside the RTV increase by 10%, all falling below the low flow threshold. Close to a 50/50 split on excursions above and below the RTV.**	**HHD operations are most likely increasing the flows by releasing excess stored water (in wet years) to prepare for the coming winter storms.**
November	**1**	**A 2% increase in the median flow. A 12% increase in variability. This distribution is the same as in October monthly means. RTV limits are exceeded 34% of the time (10% increase over without project conditions).**	**HHD operations are mitigating storm events by reducing peak flows and delaying timing, with no change in overall storm volume. Again close to 50/50 split on excursions. The only difference between October and November is the less significance of the shift in the median flow.**
December	**1**	**A 7% decrease in the median flow, with a 19% increase in variability over without project conditions. RTV limit exceedances are distributed 50/50 between low/high flow thresholds.**	**Not much significance, except that HHD flood management operations are in effect.**
Group 2: Magnitude of Mins/Maxs			
3-day Min	**4**	**Variability is significantly reduced. The 16th and 84th percentile range reduced from 99 cfs ~ 174 cfs to 99 cfs ~ 142 cfs. The median 3-day low flow was reduced 12% as well. All of the unusually higher low flows (upper range) are reduced to flows within the RTV. Overall, the range of 3-day minimum flows frequency in the RTV increased 60%.**	**While there were only 2 less instances of unusually low flows over without project conditions, the entire upper range of 3-day annual minimums has been reduced. Inter-annual variability is greatly reduced, resulting in an index of change of 4. The presumed cause of the decrease in variability is HHD operations augmenting low flows to offset TPU diversions**
7-day Min	**3**	**Distribution shifts down 12%. Variability decreases slightly. Relative to without project conditions, there are almost twice as many 7-day low flows below the RTV (or 16th percentile). Again all higher flows in the distribution are reduced to a value within the RTV.**	**While the overall number of excursions outside the RTV are minimal, there is a complete shift in distribution. Even with all these changes, the index of change is 3. This may be an example of how this technique of reducing all statistics to a single number loses descriptiveness and may need adjusting. The significance placed on the net**

Table Hydro-5 Summary Comparison of without HHD/TPU Projects and with Projects IHA\RVA Groups	Index of Hydrologic Change	Results of median and RTV (Range of Typical Values) distribution analysis	Comments
			percent change in RTV counteracts the obvious shifting of distribution. Most likely cause of this is the HHD operations attempting to augment flows, but inadequately compensating TPU's diversion.
30-day Min	**4**	**Moderate 19% decrease in the median, variability remains similar. Excursions outside the RTV almost double and all on the low end. There are over 3 times more flows below the defined RTV. The upper threshold of flows are reduced from a frequency of 5 to 2. Variability with and without projects is low.**	**Similar comments to the 3-day and 7-day minimums, except the 30-day low flow experiences the most dramatic shift of all defined durations. Here the index of change is 4. One percentage point more of a shift in the median, and the index level would be a 5. With the similarity of 30-day durations and the monthly means, they are similar effects in river dynamics for the low summer months. Again, most likely cause of this is the HHD operations attempting to augment flows, but inadequately compensating TPU's diversion.**
90-day Min	**4**	**A shift down of 15% in the median, overall distributions remains same, relative to the magnitude of the RTV. Because variability is very low regardless of with or without projects, any shift in the distribution results in significant changes in the defined ranges above and below the RTV. Distribution shifts are very similar to the 30-day minimum flows.**	**This duration of low flow statistics could be also labeled seasonal low flows. Since typical seasons are in 3-month intervals, +/-.**
3-day Max	**3**	**Only a slight shift down of 4% in the median. Variability is reduced 49%, with an obvious effect of reducing excursions outside the RTV. Overall excursions below the 16th or above 84th percentiles are reduced 80%, with all excursions in without- projects reduced to flow rates within the RTV. Similarly, 3 out of 5 (60%) excursions below the 16th are raised to levels within the RTV.**	**The concentration or reduction in distribution of the 3-day maxima strongly suggests HHD flood management operations are the cause. An Index of change for the shifts is calculated to be 3. This seems to be consistent with the fact that it is hard to say how much habitat is lost to lack of channel migration, organic debris loadings, etc.**
7-day Max	**2**	**With a 1% decrease in the median, a 8% decrease in the dispersion of the distribution-- the distribution shifts are**	**Only the higher events within the upper range are reduced. Most other hydrologic changes are**

Table Hydro-5 Summary Comparison of without HHD/TPU Projects and with Projects IHA\RVA Groups	Index of Hydrologic Change	Results of median and RTV (Range of Typical Values) distribution analysis	Comments
		moderate at best. With 40% of the high flow excursions reduced to RTV levels, and some shift of RTV flows to below the 16th percentile (20%), overall there is a 10% decrease in excursions outside the RTV.	**minimal. HHD flood management operations are becoming more like assumed natural conditions. There is no significant suggestion of influence by TPU's diversion. As a result, an Index level of 2 is given.**
30-day Max	**1**	**The median has increased 1%, and the spread in distribution has decreased by 50 cfs on each end of the RTV (4% in total). With the averaging of the 30-day statistic, distribution shifts in the maxima are minimal. 1 excursion from above and below the RTV are reduced to within RTV levels.**	**Of the N-Day duration statistics, the 30-day maxima shows the least significant change of all. HHD operations are reducing average flood flows, and augmenting any lower flows as a result of natural or TPU diversion. Index of Hydrologic change is 1.**
90-day Max	**2**	**The median of the 90-Maxima has shifted 4% down, dispersion of the distribution increases 12%. Overall excursions outside the bounds of the RTV increase 30% over without project conditions. A slight shift in the upper and slightly less than moderate shift in the middle distributions, results in almost doubling of the excursions in the lower distribution.**	**As with a majority of longer time period averages, the dispersion of distribution has increased but mostly in the lower end of the range. It is difficult to definitively state who is the cause of the shifts without identifying specific operations of both HHD and TPU. However, the shifts in distributions suggest TPU influence more than HHD operations. Index of hydrologic change is set to 2.**
Group 3: Timing of Annual Mins/Maxs			
Julian date of Annual Min	**3**	**There is a 20 day shift from mid September to late August in the median of annual minimums. Expansion of the distribution increases 19%, but in the lower range. Over 3 times more occurrences of annual minima occur earlier than August 28 and half of the upper range excursions were shifted within the RTV. Overall this constitutes a 73% increase of excursions.**	**Even though the generated without projects flow regime has been determined inadequate at this point and time for 1-day minima comparisons, the *timing* of the annual minima and maxima most likely would remain the same even using a 3-day average. Besides the shifting of the distribution, not much can be said about the impacts and their causes. A potential modification to this may be some type of overlay of timing of the annual minima with the timing of specific salmonid life stages.**

Table Hydro-5
Summary Comparison of without HHD/TPU Projects and with Projects

IHA\RVA Groups	Index of Hydrologic Change	Results of median and RTV (Range of Typical Values) distribution analysis	Comments
Julian date of Annual Max	**2**	**Virtually no change in the average timing of the annual maxima or it's RTV magnitude. With January 7 as the median date for the annual maxima, there is only a slight increase in excursions outside the Range of Typical Values, or days in this case. The RTV based on without projects, is between December 1 and January 30.**	**Not much change. When a large event occurs, it still occurs, just less in magnitude. The only reason the Index of Hydrologic Change is greater than 1 is because a 40% increase in excursions later than January 30. Everything else tends to an Index of 1.**
Group 4: Number and duration of excursions < 75% (302 cfs) and > 25% exceedance (1292 cfs)			
Low Pulse Count	**2**	**A 11% decrease in the median of pulse counts, may be misleading. The pulse counts reduce from 4.5 to 4.0 per year. The magnitude in RTV increases by one pulse more per year on the upper threshold, and decreases by one pulse count per year on the lower threshold.**	**Not much value is added by this version of the statistic. The defined threshold of 302 cfs is either equal to or greater than the median summer month flows. Conclusions are therefore similar to those for the summer monthly means.**
High Pulse Count	**3**	**The median annual pulse count increase slightly from 10.5 to 11 per year, with the lower end of the RTV decreasing from 9 to 7 pulses per year. Excursions outside the RTV increase 50% with two-thirds of that increase in the lower range of unusually low values.**	**The 25% exceedance flow is less than the mean monthly flow for winter storm months. In order to make this statistic more unique with more description power, a reevaluation of the exceedance threshold should be conducted.**
Low Pulse Duration	**4**	**Low pulse durations and distribution increase for with-project conditions. With similar increases, the median duration and the magnitude of the distribution increase 49% and 41%. The shift in distribution masks the overall increase in excursions outside the RTV to a mere 10%. However, the distribution experiences severe shift. All unusually low events become typical events, and unusually high events (above the 84^{th} percentile) slightly more than double in frequency.**	**The more interesting change here is the shift in distribution, and not just the excursions outside the RTV. As a result of the major shift, the cumulative distribution has shifted as well. The most likely cause of this shift is the TPU diversion not fully being compensated for by HHD operations. Based on the Index of Hydrologic Change, the median shift and the overall shift in distribution evaluate to a high level of change with an index of 4.**
High Pulse Duration	**2**	**The average duration of a high pulse decreases by 8%, while the upper threshold of the RTV decreases 23%. Shorter annual average pulse durations of less than 6-**	**Similar to low pulse durations, the overall number of excursions outside the RTV are nearly the same without- and with- projects. Because the High Pulse**

Table Hydro-5 Summary Comparison of without HHD/TPU Projects and with Projects IHA\RVA Groups	Index of Hydrologic Change	Results of median and RTV (Range of Typical Values) distribution analysis	Comments
		days double in frequency. The frequency of pulse durations greater than 11.4-days reduces to a single year with an average above 11.4-days.	**threshold is similar to monthly spring flows, the shifts in the pulse duration distribution resemble that of spring months as well. It is unclear as to the cause of this shift except for the general comments that it is most likely a result of the combination of HHD operations and TPU diversion. With only one significant change, the index of hydrologic change evaluates to 2.**
Group 5: Rates and Annual number of flow rises and falls			
Fall Rate, cfs/day	**2**	**While the difference of thresholds remains relatively the same, the median of fall rates increases 12%. 60% of the fall rates that were less than the typical rate increased to within the RTV (a 9% increase in frequency of years within the RTV). Overall excursions above and below the RTV, decreased 20%.**	**Fluctuations from day to day have increased on average for the 32 years of analysis. Years that average daily fluctuations less than 99 cfs decrease from 5 to 2, with the RTV defined as between 99 cfs and 223 cfs. This suggests that the HHD operations and TPU diversion may be in some discord with each other. In any case, with the small change in median fall rates, the small change in the RTV, the index of hydrologic change is assessed to be 2.**
Rise Rate cfs/day	**5**	**Rise rates decrease 22% and a decrease in the magnitude of change of 12%. Magnitudes of the Rise rates decreases such that the frequency of rates that are classified as unusually low (below the 16th percentile), more than double (2.4 times). With this distribution shift, the overall change in excursions outside the RTV increase, 40%.**	**As would be expected the average rise rate from day to day is reduced. Most likely a result of HHD operations. The ecological implications of such changes in the hydrologic regime are not clear; however, this suggests that on the whole the river may be less dynamic.**
Fall Count (1 cfs or larger)	**N/a**	**A 12% decrease in counts, 24% decrease in variability. A complete shift in distribution, such that the relative 84th \16th percentiles from without- , and with- projects almost have no overlap. The 16th percentile (203 cfs) in the without projects conditions practically equal the 84th**	**While there appear to be substantial changes with projects in place, the significance of evaluating 1-cfs changes from day to day is uncertain. This statistic as defined, can give an overview of the general dynamism but not much more than that.**

Table Hydro-5 Summary Comparison of without HHD/TPU Projects and with Projects			
IHA\RVA Groups	Index of Hydrologic Change	Results of median and RTV (Range of Typical Values) distribution analysis	Comments
		percentile (204 cfs) with project conditions. As a result, there are 2.7 times more excursions overall with-project conditions, all of which in the lower range.	
Rise Count (1 cfs or larger)	**N/a**	**A 6% decrease in the median, a 32% increase in range, and a 40% increase in overall excursions outside the RTV. Similar to but not as extensive as the Fall Counts, the Rise counts shift from higher frequency to a lower frequency per year.**	**Again not much can be gained from this statistic (*see Fall Count comments above*). The increase in distribution is primarily only in the lower end. The 16th percentile frequency decreases from 120 to 112 events per year. The 84th percentile remains relatively the same. What can be said is the general concept of HHD operations are moderating flow rate increases. TPU diversion compounds the decrease in rise rates. To balance out the impacts with projects in place, it would take a day-to-day operations link between HHD and TPU.**
Fall Count (10% Rule)	**2**	**As expected the average frequency of annual events decreased 10%, with a 25% decrease in variability. With the small shift in the median and the large decrease in variability, the overall change in excursions outside the RTV decrease with projects in place. This is accountable by a 60% decrease in frequency of counts greater than the 84th percentile and no change in the frequency of events below the 16th percentile.**	**Given the overall variability decrease in with- project conditions, this may suggest that HHD operations are augmenting TPU diversions and naturally occurring drops in flow rates for most years. In fact, for years that may be naturally experiencing a higher number drops in the flow regime the HHD operations may be over mitigating based on without projects conditions.** **While this "10% Rule" is designed to provide greater insight with respect to without- and with-projects, it may not be fully optimized for ecological relevance.**
Rise Count (10% Rule)	**3**	**The number of rise rates that exceed the 10% rule decrease on average 11%. The relative variability between without- and with- projects remains the same. 80% of the unusually more frequent years have been reduced in frequency to match more typical values (RTV).**	**In review of the changes and shifts in distribution compared to the Fall Count (10% Rule), one would expect the same level of hydrologic change. This illustrates the effect of weighting of particular factors of change. Since the median change is above**

Table Hydro-5
Summary Comparison of without HHD/TPU Projects and with Projects

IHA\RVA Groups	Index of Hydrologic Change	Results of median and RTV (Range of Typical Values) distribution analysis	Comments
		In addition, the number of years that have been identified as an unusually low year have increased 40% (or from 5 years to 7 years). This shift in distribution nets an overall decrease of 19% in excursions outside the RTV.	**10%, the significance of change in the distribution is considered moderate or a "3" based on the algorithm as illustrated in Figure 1.**

HOWARD HANSON DAM REFILL CRITERIA AND CONSIDERATIONS

Target Wild Steelhead Redd Incubation Flow: Maximum of one (1) foot stage drop from Season Spawning Flow at Auburn.

Season Spawning Flow: Average of highest ten (10) Daily Spawning Flows measured at Green River near Auburn (USGS 12-1130).

Daily Spawning Flow: Actual mean daily flow.

Steelhead Spawning Period: April 1 through June 15.

Steelhead Incubation Period: April 1 through at least July 31.

Ramp Rate Criteria: To reduce loss by stranding of salmon and steelhead fry, interim ramp rate criteria for flows under operational control of the project (does not apply to natural freshets) are as follows:

- February 16 to May 31* (salmon fry)
  - Daylight rates (1 hour before sunrise to 1 hour after sunset): No ramping.
  - Night rates (1 hour after sunset to 1 hour before sunrise): 2 inches per hour.
- June 1* to October 31 (steelhead fry)
  - Daylight rates: 1 inch per hour.
  - Night rates: 1 inch per hour.
- November 1 to February 15
  - Daylight rates: 2 inches per hour.
  - Night rates: 2 inches per hour.

* Date of shift from spring to summer criteria may require adjustment based on actual timing of steelhead fry emergence.

2.2 SEDIMENT TRANSPORT

2.2. SEDIMENT TRANSPORT

EXECUTIVE SUMMARY

Sediment and its transport from source to the downstream reaches of the river is an important process that produces and maintains salmonid habitat. In a properly functioning system, sediment provides a quality substrate for salmon egg incubation, food source production and cover from predators. When the process is disrupted, as with excessive landslides or dam construction, fish habitat degradation results.

Forestry activities, such as logging, road construction and bank stabilization in the Upper Green River sub-watershed have increased both the rate of mass wasting and the amount of fine sediment input from road surfaces. Aggradation of low gradient reaches has in some instances resulted in flows going subsurface during the late summer (USFS 1996). Gravel samples taken from within the upper watershed also contain moderate to high levels of fine sediment (Fox 1996).

The effects of the increased coarse sediment yields do not extend into the middle and lower Green River sub-watersheds because of the presence of Howard Hanson Dam (HHD). The dam effectively prevents delivery of coarse sediment from the upper basin to downstream reaches, although suspended sediment continues to be carried past the dam. The elimination of the coarse sediment supply from the upper basin is believed to have had a profound effect on habitat conditions in the Middle Green River sub-watershed. The upper basin formerly supplied over 90 percent of the alluvial gravel deposited in the Green River floodplain downstream of Flaming Geyser State Park at RM 45. The reduction in gravel supply has resulted in a decrease in the amount of sediment stored within the channel both above and below the Green River gorge (RM 45 to RM 57). Flows released from HHD during the winter are sufficient to transport coarse sediment, thus material stored in the channel is carried downstream without being replenished, and the channel incises until an armor layer formed of coarse sediments that cannot be readily transported develops. Based on an analysis of channel morphology and historic air photo sequences, armoring is believed to have altered the reach between RM 61 and RM 57, and may be beginning to affect the river downstream of the Green River gorge (Perkins 1993; Perkins 2000). As armor layer formation progresses downstream, spawning gravels are lost, and channel incision may reduce the amount of available rearing habitat by increasing the amount of time that side channels are disconnected from the mainstem. Figure Sed-1 provides a conceptual illustration of the effect of HHD on downstream sediment transport.

The reduction in the supply of sediment from upstream reaches has increased the significance of streamside landslides downstream of the dam. Landslides in the Middle Green River sub-watershed contribute material that is predominantly sand size or smaller (Perkins 1993; Perkins 1998), and, because of the reduction in coarse sediment inputs from upstream, that sand sized material now comprises a much larger proportion of the total bedload. The majority of streamside landslides occur where the channel flows adjacent to the steep valley side slopes downstream of Flaming Geyser Sate Park. One such slide, near RM 43, was reactivated by a major flood in 1996 (Cropp 1999). This slide is estimated to have delivered up to 50,000 cubic yards of sediment to the channel (Perkins 1998). This slide has been linked to pool filling and degradation of spawning gravels for at least a mile downstream (Cropp 1999).Several other events have effected the sediment regime of the lower Green River. Diversion of the sediment-rich White River in 1906 dramatically reduced the supply of sediment to reaches downstream of RM 32. An analysis of floodplain deposits suggest that the White River formerly supplied approximately 75 percent of the sediment to the river downstream of RM 32 (Mullineaux 1970). In response to the diversion of the White River, the Green River downstream of Auburn has formed a new, smaller floodplain within the former floodplain of the combined White and Green Rivers. Since then, development and erosion in tributary channels as a result of increased peak flows have increased the amount of fine sediment delivered to the lower river from smaller basins.

KEY FINDINGS:

UPPER GREEN RIVER SUB-WATERSHED (RM 64.5 TO RM 93)

Possible Impacts to Salmonids Resulting from Changes in Sediment Transport Regime in the Upper Green River Sub-watershed

Currently the upper watershed doesn’t have access for adult anadromous salmonids, future adult transport to the upper watershed is anticipated.

Spawning and Incubation

- Road related sediment yields exceeded 50 percent of background in several subbasins in the Lester WAU. In addition, the volumetric proportion of fine sediment was elevated in potential spawning gravels collected from various sites throughout the Lester WAU. High levels of fine sediment smother or trap incubating eggs and alevins and could limit the reproductive success of salmonids. The exact sediment concentrations are being compared to threshold values known to impact the reproductive success of salmonids.

- Storage of floodwaters behind Howard Hanson Dam reduces upstream river flow velocities resulting in at least 7.2 miles of river channel sedimentation to an extent that is detrimental to salmonid egg incubation.

Juvenile Rearing

- Landslides and mass wasting associated with logging practices has led to coarse and fine sediment inputs that fill pools and dramatically increase width to depth ratios in streams and rivers, reducing the area of habitat available for juvenile salmonid rearing. Landslides have negatively impacted juvenile salmonid rearing habitat in 2.6 of the 4.7 miles of stream surveyed in the Lester WAU.

MIDDLE GREEN RIVER SUB-WATERSHED (RM 32 TO RM 64.5)

Spawning and Incubation

- Entrapment of coarse volcanic origin cobbles and gravels behind Howard Hanson Dam has resulted in a reduction of suitable spawning gravels in Middle Green River sub watershed, particularly in the reach between RM 64.5 and RM 57.

- Large amounts of fine sediments are being released from slides in this sub watershed and their downstream deposition are detrimental to the successful spawning and incubation of salmonid eggs and alevins.The reduced coarse sediment supply is believed to have led to river channel incision. This could reduce the connectivity of important off-channel salmon spawning habitat such as side channels, groundwater fed channels and tributaries.

Juvenile Rearing

- The reduced coarse sediment supply has led to river channel incision. This has reduced the connectivity of off channel rearing habitat such as side channels, groundwater fed channels/ponds and tributaries.

- Increased fine sediment inputs have been observed to fill pools and the interstitial spaces within substrates near RM 43. This reduces the amount and quality of habitat (i.e., reduces food supply by lowering benthic invertebrate productivity, fills interstitial spaces used as cover) available for rearing juvenile salmonids. Although such effects have not been document, similar impacts are expected to have resulted downstream of other slide zones in this reach.

LOWER GREEN RIVER SUB-WATERSHED (RM 11 TO RM 32)

Spawning and Incubation

- Diversion of the White River into the Puyallup River Watershed substantially reduced the delivery of coarse sediment to the lower Green River. This also may have reduced the availability of suitable anadromous salmonid spawning habitat.

Juvenile Rearing

- Increased fine sediment delivery from upstream reaches and urbanized tributaries is filling pools and substrate interstitial spaces, thereby reducing the amount and quality of habitat available for rearing juvenile salmonids.

- As a result of the diversion of the White River and Cedar/Black River the Green River bed and floodplain has lowered. This lowering has disconnected off channel juvenile salmonid rearing habitat. This change has been compounded further and masked by the construction of levees.

MAJOR TRIBUTARIES TO THE GREEN RIVER

Upstream Migration

- The increased sediment delivery to alluvial fans and low gradient reaches of the Green River, in combination with the decrease in low flows impedes adult chinook attempting to migrate upstream into tributaries.

Spawning and Incubation

Increased fine sediment delivery and deposition into low gradient reaches of the tributaries may be sufficient to reduce salmonid reproductive success. High levels of fine sediment can smother or trap incubating salmonid eggs and alevins.

Juvenile Rearing

- The increase of fine sediment inputs may fill pools and the interstitial spaces within substrate. This would result in a reduction of the amount and quality of habitat (i.e., reduces food supply by lowering benthic invertebrate productivity, fills interstitial spaces used as cover) available for rearing juvenile salmonids.

DATA GAPS

- Watershed-wide sediment contribution information at the sub-watershed scale was not available.The downstream progression of the armor layer on the mainstem has not been estimated for almost ten years.

OVERVIEW

Sediment inputs, transport capacity and vulnerability to changes induced by human activities in WRIA 9 are largely a result of the geologic and topographic characteristics of the basin. The Green River basin is primarily comprised of four types of geological deposits: volcanic rocks forming the Cascade Mountains, sedimentary rocks of the Puget Group, glacial deposits from the Pleistocene, and alluvium deposited by rivers since the last glaciation. Bedrock in the Upper Green River sub-watershed is formed of volcanic rocks such as basalt and andesite. Resistant volcanic rocks are an important source of suitable spawning gravel and cobbles that are supplied to the Green River channel primarily through episodic mass-wasting events. Samples of alluvial materials collected downstream of Flaming Geyser Sate Park indicate that over 90 percent of the alluvium was derived from volcanic parent materials (Mullineaux 1970).

Downstream of HHD in the upper portion of the middle Green sub-watershed, bedrock consists primarily of the Puget Group, a series of soft and erodible rock units that were deposited in a large coastal plain around 50 to 60 million years ago (Mullineaux 1970). These deposits are exposed in the Green River Gorge. The sandstones and mudstones of the Puget Group are easily broken down into fines and do not persist as cobble and gravel-sized particles after entering the river (Dunne and Dietrich 1978).

During the Pleistocene (from about 1 million years to approximately 12,000 years ago) large lobes of glaciers up to 3,000 feet thick extended south from British Columbia and covered the lowlands around Puget Sound. These glacial advances and retreats scoured existing bedrock and left a complex array of glacial outwash, till, alluvium, and lacustrine deposits (Mullineaux 1970). Glacially derived, unconsolidated sediments cover most of WRIA 9 downstream of the Green River Gorge and are the main source of gravel in the major tributaries draining to the Middle Green River sub-watershed.Since the Pleistocene, the Green River incised a new meandering route through the unconsolidated glacial sediments to around Auburn, where it was joined by the White and Cedar/Black Rivers. Creation of a wide, alluvial valley effectively disconnected the Green River from the glacial deposits, except at isolated locations where the channel impinges directly on the steep valley walls.Around 5,000 years ago, the Osceola Mudflow swept down from the slopes of Mount Rainier through the valley of the White River. This major geological event covered the lowlands from Enumclaw to approximately 4 miles north of Auburn with mudflow deposits up to 75 feet thick, well into the present Lower Green River sub-watershed (Mullineaux 1970). The combined effects of these depositional processes eventually filled in the Duwamish embayment to form a broad lowland characterized by meandering river channels and extensive wetlands.

METHODS AND APPROACH

The investigation of alterations in the sediment delivery and transport regime of the mainstem Green River was based on a review of existing literature. The following section presents the results of the literature review for each sub-watershed.

RESULTS

UPPER GREEN RIVER SUB-WATERSHED (RM 64.5 TO RM 93)

In the Upper Green River sub-watershed, the headwater streams with gradients in excess of four percent can generally transport more sediment than they receive, and are typified by bedrock and boulder-dominated channels. Under undisturbed conditions, coarse sediments enter the stream system by means of periodic mass wasting and rock fall, and collect in the lower gradient reaches of the upper valley area, where narrow, discontinuous alluvial deposits are created and reworked. Fine sediment production in the Upper Green River sub-watershed is low relative to other nearby, glacially-fed rivers such as the White River (Mullineaux 1970).

FOREST MANAGEMENT

Modeling of the mass wasting potential in the Upper Green River sub-watershed suggests that approximately 15 percent of the basin has a high mass wasting potential rating, and 69 percent of the basin has a moderate mass wasting potential rating (USFS 1996). Large scale logging began circa 1880-1910 in the Lower and Middle Green River sub-watersheds and rapidly moved upstream into the Upper Green River sub-watershed between 1910 and 1930. Logging has extended to the highest portions of the upper basin in recent years. Private lands were logged extensively in the 1960s and 1970s. Forest management activities have increased the delivery of coarse and fine textured sediment to the mainstem Green River. Many of the landslides identified during watershed analysis were associated with timber harvest or logging roads (Reynolds 1996). Landslide inventories conducted as part of Watershed Analysis have identified a suite of landforms with varying rates of mass wasting (Reynolds 1996; Ryan 1999).Debris flows and dam-break floods, such as those described by the Channel Assessment for the Lester Watershed Analysis (Cupp and Metzler 1996) have scoured a number of tributary channels. In the Lester Watershed Administrative Unit (WAU), over half of the channel segments surveyed for the Fish Habitat Module (2.6 miles of the total 4.7miles) had been disturbed by debris flows or dam-break floods at some time in the past (Fox 1996). Coarse sediment produced by mass wasting is routed downstream to low-gradient response reaches. Excessive coarse sediment inputs can fill pools and dramatically increase width to depth ratios. Such impacts were noted in portions of the mainstem Green River dominated by alluvial processes, and on floodplain tributaries and alluvial fans (Cupp and Metzler 1996).

Watershed analysis also suggests that forest roads have increased the production of fine sediment. Fine sediment increases greater than 50 percent are generally considered to be detectable and have the potential to adversely impact aquatic habitat (WFPB 1997). The Champion Creek, Rock Creek and Friday Creek subbasins within the Lester WAU each had estimated sediment yield increases of between 50 to 94 percent (Table Sed-1). Preliminary results of the draft Upper Green/Sunday Watershed Analysis indicate that the Upper Sunday, West, Snow, Lower Sunday, Pioneer, Tacoma and Lower Green River subbasins also had road-related fine sediment increases that were greater than 50 percent of the background sediment delivery rate (Evans 1997). Persistent increases in fine sediment would be expected to result in increased deposition of fines in pool tails and side channel pools. Moderate to high levels of fines (>12 % by volume) were noted in 8 of the 9 samples collected from various channel locations within the Lester WAU (Fox 1996), thus management-related sediment yield increases are a concern in the Upper Green River sub-watershed (USFS 1996).

HOWARD HANSON DAM

The impoundment of water behind HHD has altered the sediment transport capacity of inundated portions of the mainstem Green River and its tributaries. As discussed in earlier, the turbidity pool behind the dam is maintained year-round. This results in decreased velocity and water slope near the dam, which reduces the river's ability to transport sediment. As a result, the 1.8 miles of channel permanently inundated by the turbidity pool is slowly being buried by fine sediment (USACE 1994).

During the fall and winter, Howard Hanson reservoir is drawn down, and outflows from the dam generally match inflows until there is a threat of a flooding. During flood control operation, outflow from HHD is restricted and water is impounded behind the dam. As the reservoir fills, the flow depth increases, velocity decreases dramatically, and the ability of the flow to transport sediment is reduced by the sharp decrease in velocity and water surface slope. Because of the rapid decrease in transport capacity, coarse sediments drop out at the upstream end of the impounded area, and only suspended material is transported past HHD. Deposited sediment has resulted in embeddedness levels of up to 100 percent in much of the 5.4 miles of seasonally inundated habitat upstream of the turbidity pool (Wunderlich and Toal 1992). Deposition of fine sediment has also affected reaches just upstream of the seasonally inundated zone, where embeddedness levels exceeded 40 percent in six of nine reaches surveyed (Wunderlich and Toal

1992). Modeling suggests that from 6,500 to 19,700 tons of gravel per year that was formerly routed from the Upper Green River sub-watershed to downstream reaches prior to construction of HHD is now depositing upstream of the dam (USACE 1998).

The majority of suspended sediments continue to be transported through the reservoir past HHD. Some of those sediments are deposited in the turbidity pool. A recent study by the USACE suggests that the turbidity pool is filling with sediment more rapidly than expected (USACE 1994) supporting the conclusion of recent Watershed Analyses (Coho 1996; USFS 1996) that fine sediment inputs have increased as a result of roads and forest management activities in the Upper Green River sub-watershed.

MIDDLE GREEN RIVER SUB-WATERSHED (RM 32 TO RM 64.5)

HOWARD HANSON DAM

Between HHD (RM 64.5) and Kanasket State Park (RM 57), the mainstem Green River was historically a moderate gradient mountain channel, with occasional gravel bars and side channels in less-confined areas. Examination of historic aerial photos (USACE 1944) revealed only sporadic large, in-channel sediment storage sites (i.e. gravel bars), most of which were located just upstream of Kanasket State Park or near Palmer junction.The construction of the Headworks did not seriously impair gravel movement to downstream reaches since the facility has a storage capacity equivalent to approximately one years supply of bedload and filled quickly following construction. However, the construction of HHD significantly reduced the supply of gravel to the Middle Green River sub-watershed. Modeling indicates that moderate flows (>1,000 cfs) are capable of mobilizing gravel and cobble size sediments in the reach between HHD and Kanasket State Park, and this is believed to have resulted in the formation of an “armor layer” downstream of the dam, as smaller sediments are transported out of the reach without being replaced by material from upstream.Between RM 57 and RM 45.6, the Green River flows through a steep gorge with a channel bed composed predominantly of bedrock and boulders. Occasional patches of gravel deposit only in protected areas along channel margins or behind large boulders. Because it occupies a steep, narrow canyon, the gorge has always functioned primarily as a sediment transport conduit between the upstream sources and downstream depositional/alluvial areas. Salmonid spawning habitat is limited compared to lower gradient, less confined reaches located downstream, but habitat in the gorge is currently used by chinook where available (Malcom 1999). The availability of gravels suitable for spawning salmonids in the canyon reach has likely decreased as a result the reduction in sediment supply caused by construction of HHD.

The lower reach of the Middle Green River sub-watershed, below RM 45.6, represents a transition zone between sediment transport and depositional processes. Historically, much of the lower reach was braided and the stream meandered freely across the floodplain (Perkins 1993). There is some evidence that the effects of HHD on gravel supply are beginning to extend downstream of the Green River gorge (Perkins 1993; Perkins 2000), an area that is now the most significant site of spawning in the mainstem Green River. Localized bank revetment construction in portions of this reach may have helped accelerate the armoring process by straightening and confining the channel, thereby increasing its sediment transport capacity.In a study of channel migration in the reach between RM 25 and RM 45, Perkins (1993) noted that changes in channel morphology upstream of RM 40.2 since 1962 are consistent with a reduction in sediment supply.

Her conclusions are based on the observation that “braided areas have diminished, the channel has narrowed [and] active sediment storage sites have decreased in size and number” since construction of HHD. In contrast, she reported that the presence of numerous large active gravel bars below RM 40.2 indicate that the sediment load continues to exceed the transport capacity there, suggesting that the reduction in sediment supply has not yet impacted that reach. Armor layer formation is estimated to be advancing downstream at 700 to 900 feet per year in the middle Green River (Perkins 1993).

It has been suggested that the effect of gravel depletion will continue to migrate further downstream over time (Fuerstenberg et al. 1996). In addition, modeling suggests that flows greater than approximately 2,000 cubic feet per second (cfs) are capable of mobilizing gravel and cobble size sediments in the middle Green river (USACE 1998). Howard Hanson Dam operations have increased the frequency and duration of flows between 3,500 and 9,100 cfs (Figure Sed-2), and this increase, in combination with the limited supply of sediment below HHD, may have increased the annual sediment transport capacity by as much as 30% (Dunne and Dietrich 1978).Impacts from changes in the hydrologic and sediment transport regimes have influenced aquatic habitats in the middle Green sub-watershed. The decreased sediment supply, in combination with the increased frequency of flows capable of mobilizing gravels may have increased the frequency of redd scour. Moreover, downstream progression of armoring will continue to reduce the availability of spawning gravel. If the channel incises as a result of armor layer formation, formerly accessible off channel habitats such as side channels, ground water channels and wall based tributaries will become disconnected at lower flows (USACE 1998). Figures Sed-3a and Sed-3b provide a conceptual illustration of the effects of gravel starvation on an alluvial gravel bed river such as the middle Green River.

LANDSLIDES

Following glaciation, the Green River rapidly cut down through the unconsolidated glacial sediments, forming a wide alluvial valley bordered by steep bluffs formed of the glacial materials (Figure Sed-5). In many areas these unconsolidated glacial sediments are composed primarily of fine-grained silts and sands. Landslides that occur where the Green River undercuts these bluffs deliver large amounts of fine sediment to the channel (Figure Sed-6a and b). While this process has been ongoing since the glaciers retreated, the recent reduction in large floods and coarse sediment inputs from upstream mean that sediment inputs from valley sideslopes in the Middle Green sub-watershed now comprise a greater proportion of the total bed material load.One such landslide located just downstream of Flaming Geyser State Park, near RM 43, was reactivated during major floods in 1996 and 1997 (Cropp 1999). Recent analysis suggests this large slide has delivered up to 50,000 cubic yards of sediment to the river (Perkins 1998). The landslide is primarily delivering sand-sized material to the river (Figure Sed-6b), and has filled pools and buried spawning gravels downstream of the site (Cropp 1999). Delivery of large amounts of sediment from that slide in 1999 has coincided with a reduction in the number of juvenile chinook caught in a nearby side channel, and may be having a significant impact on fry emergence and survival (Hilgert 1999).

LOWER GREEN RIVER SUB-WATERSHED (RM 11 TO RM 32)

DIVERSION OF THE WHITE RIVER

When the White River historically joined the Green River near RM 31, it is estimated to have contributed roughly 75 percent of the total sediment load to the lower basin (Mullineaux 1970). Since the diversion of the White River and the Cedar/Black River, the channel downstream of RM 32 has narrowed by forming a new floodplain within the old channel (Perkins 1993). The new floodplain surface is at least 7 feet lower than the former floodplain (Dunne and Dietrich 1978).While the White River previously contributed a great deal of coarse and fine sediment to the Lower Green River sub-watershed, the majority of the coarse material (gravel and cobble) deposited on an alluvial fan that does not appear to have extended downstream much beyond RM 27 (Dunne and Dietrich 1978). Southwest of Renton, valley floor deposits are composed of silt, clay and fine sand interbedded with peat (Mullineaux 1970). With the exception of coarse materials associated with a smaller alluvial fan that formed near the mouth of the Cedar/Black Rivers, these deposits of fine material form the substrate of the lower Green/Duwamish River (Mullineaux 1970). Therefore, it is unlikely that this sub-watershed ever provided important spawning habitat for anadromous salmonids downstream of RM 27. Spawning surveys conducted between RM 27 and RM 30 indicated that use by spawning chinook is currently low compared to upstream reaches (Cropp 1999).

A number of studies suggest that erosion in small tributary basins has increased as a result of increased peak flows and urban development (KCM 1986a: KCM 1986b; Entranco et al. 1997; Booth et al. 1994). While coarse sediment eroded from these small, low energy streams probably deposits in local storage reaches, the amount of fine sediment delivered to the lower Green River from small tributaries has probably increased. No significant changes in channel location, pattern, or bedform have been reported as a result of increased fine sediment inputs from landslides or small tributaries. However, pool infilling has been observed in this segment (Malcom 1999), and increased fine sediment delivery may be impacting water quality, as discussed in Chapter 1.

MAJOR TRIBUTARIES TO THE GREEN RIVER

URBANIZATION AND INCREASED STORMFLOWS

The major tributaries are located in the lower part of the basin that was formed from glacial outwash. Slopes there are relatively gentle and sediment is input primarily by fluvial erosion as the channels slowly incise through the unconsolidated sediments. Major tributary streams have low-relief headwaters with frequent lakes and wetlands, then briefly flow through deep, steep-sided ravines where they cross the steep valley sidewalls formed by the Green River. When the tributary channels reach the flat alluvial floodplain of the mainstem, they become low gradient pool-riffle type channels that meandering widely before joining the Green River. Both Newaukum and Soos Creek have formed small alluvial fans where they enter the Green River Valley (Mullineaux 1970). Because it joins the mainstem Green River almost immediately after emerging from the steep canyon reach, Newaukum Creek represents an important source of sediment to the middle Green River (Perkins 1993). In contrast, most of the coarse sediment transported by Soos Creek settles out in low gradient reaches prior to reaching the Green River (King County 1989).Urban development increases sediment inputs by exposing soils to surface erosion, and by removing stream bank vegetation which is important for filtering fine sediments and maintaining bank stability. In addition, increased peak flows have a higher erosive ability, and require larger channels, which results in accelerated bank erosion. Localized increases in erosion and sedimentation are described in the Soos Creek Basin Plan (King County 1989) and Mill Creek Basin Study (King County1986). Anecdotal evidence suggests that sediment yields from Newuakum Creek have also increased, primarily as a result of livestock grazing. Sediment produced from increased erosion in the headwater reaches settles out in short low gradient reaches, or where the main tributary channel crosses the Green River floodplain. Increased sediment yields degrade spawning gravel and fill pool or slough habitat utilized by rearing salmonids.

LIST OF TABLES

Table SED-1. Hydrologic changes in tributaries to the Green River, Upper Green Subbasin.

LIST OF FIGURES

Figure SED-1: Green River gravel conveyor belt.

Figure SED-2: Channel Incision/Armoring.

Figure SED-3a: Natural River: Habitats.

Figure SED-3b: Incised River: Worst Case.

Figure SED-4: Daily flow duration curves, USGS gage 12113000 Green River near Auburn, prior to and after construction of Howard Hanson Dam.

Figure SED-5: Topographic map of the middle Green River basin illustrating wide alluvial valley and steep valley walls.

Figures Sed-6a and 6b: Landslide photos

Table SED-1. Hydrologic Changes in Tributaries to the Green River, Upper Green Subbasin (RM 64.5 to Headwaters) as Predicted Using the Hydrology Module of the Washington Forest Practices Board Manual (1997).

Stream Name	D.A (mi^2)	Peak Flow Increase[1] (%)	Sediment Yield Increase	Reference
Wolf Creek		<10%	44%	Coho1996
Green Canyon Creek		<10%	39%	Coho1996
Champion Creek	6.61	<10%	92%	Coho1996
Rock Creek		<10%	92%	Coho1996
McCain Creek		<10%	35%	Coho1996
Lester		<10%	1%	Coho1996
Sawmill Creek	7.9	>10%	15%	Coho1996
Friday Creek		>10%	102%	Coho1996
East Creek		<10%	49%	Evans 1997
West Creek		<10%	77%	Evans 1997
Snow Creek		<10%	65%	Evans 1997
Upper Sunday Creek		<10%	70%	Evans 1997
Lower Sunday Creek		<10%	95%	Evans 1997
Pioneer Creek		<10%	109%	Evans 1997
Lower Green River		<10%	78%	Evans 1997
Tacoma Creek		<10%	78%	Evans 1997
Twin Camp Creek		<10%	33%	Evans 1997
Upper Green River		<10%	12%	Evans 1997
Intake Creek		<10%	28%	Evans 1997

This problem is the result of the disruption of two important natural processes by Howard Hanson dam; sediment transport and flow regime. Flows have been manipulated by the dam to reduce large floods, but this results in an increase in medium sized gravel scouring events. The gravel is used by salmon for spawning and egg incubation as well as for the production of juvenile food (benthic invertebrates). The gravel that has moved downstream cannot be replaced due to the capture of gravel at the dam. The result is the downstream migrating sediment void shown in this "conveyor belt" diagram.

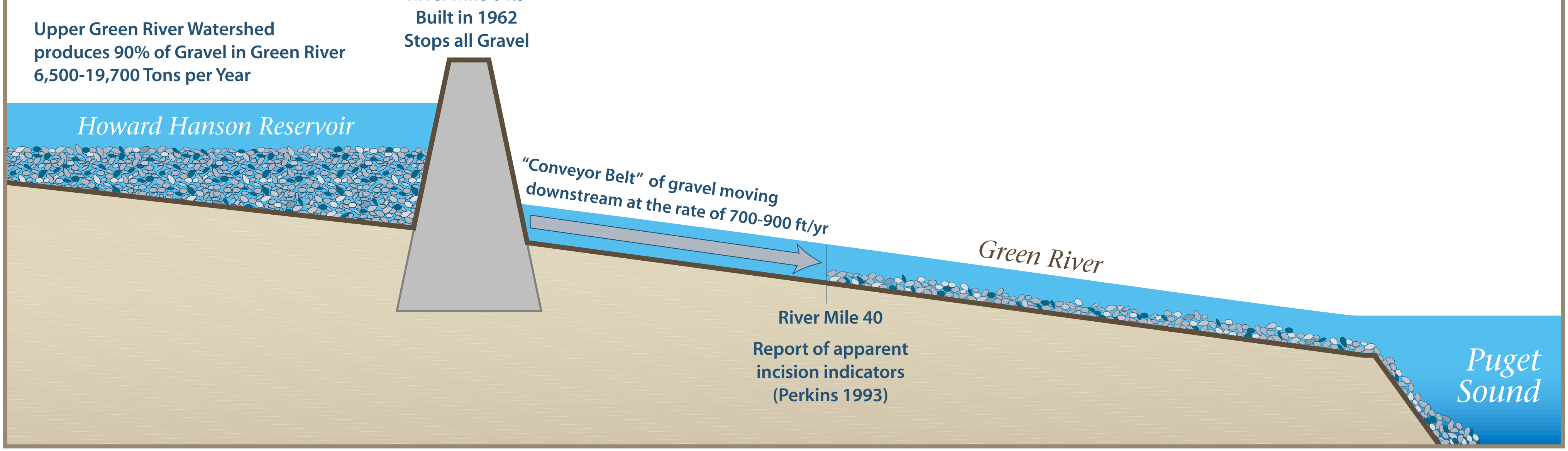


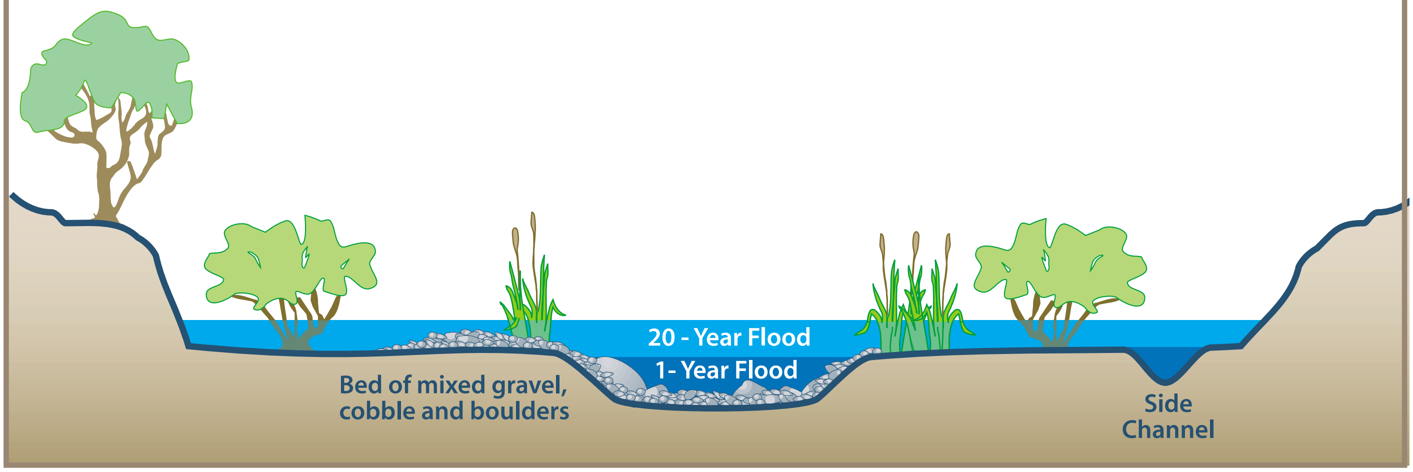
Figure SED-1

Green River Gravel "Conveyer Belt"

Poster produced by:
King County DNR
Visual Communication/GIS Unit
0010 Green Gravel Convey.ai WG,lp

Natural River Channel

The middle reach of the Green River (RM 61-32), downstream of Howard Hanson dam to Highway 18 is showing signs of degradation by a condition called armoring.



Incised River Channel

Armoring is the removal without replacement of gravel resulting in a streambed surface layer composed primarily of large cobbles and boulders. If this condition continues it could result in significant narrowing and deepening of the channel, called channel incision. Incision and armoring can act in concert to eliminate important salmon habitat.

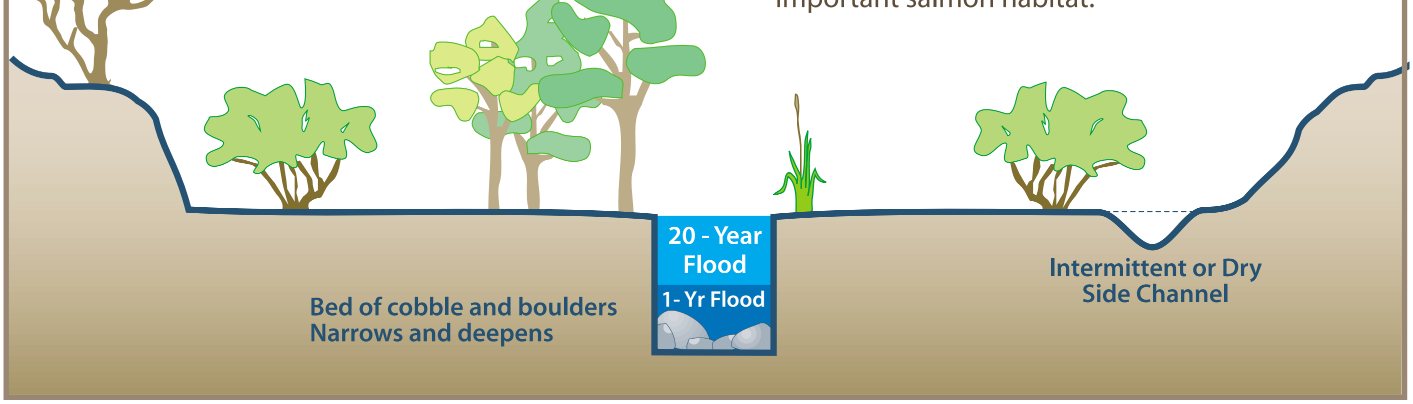
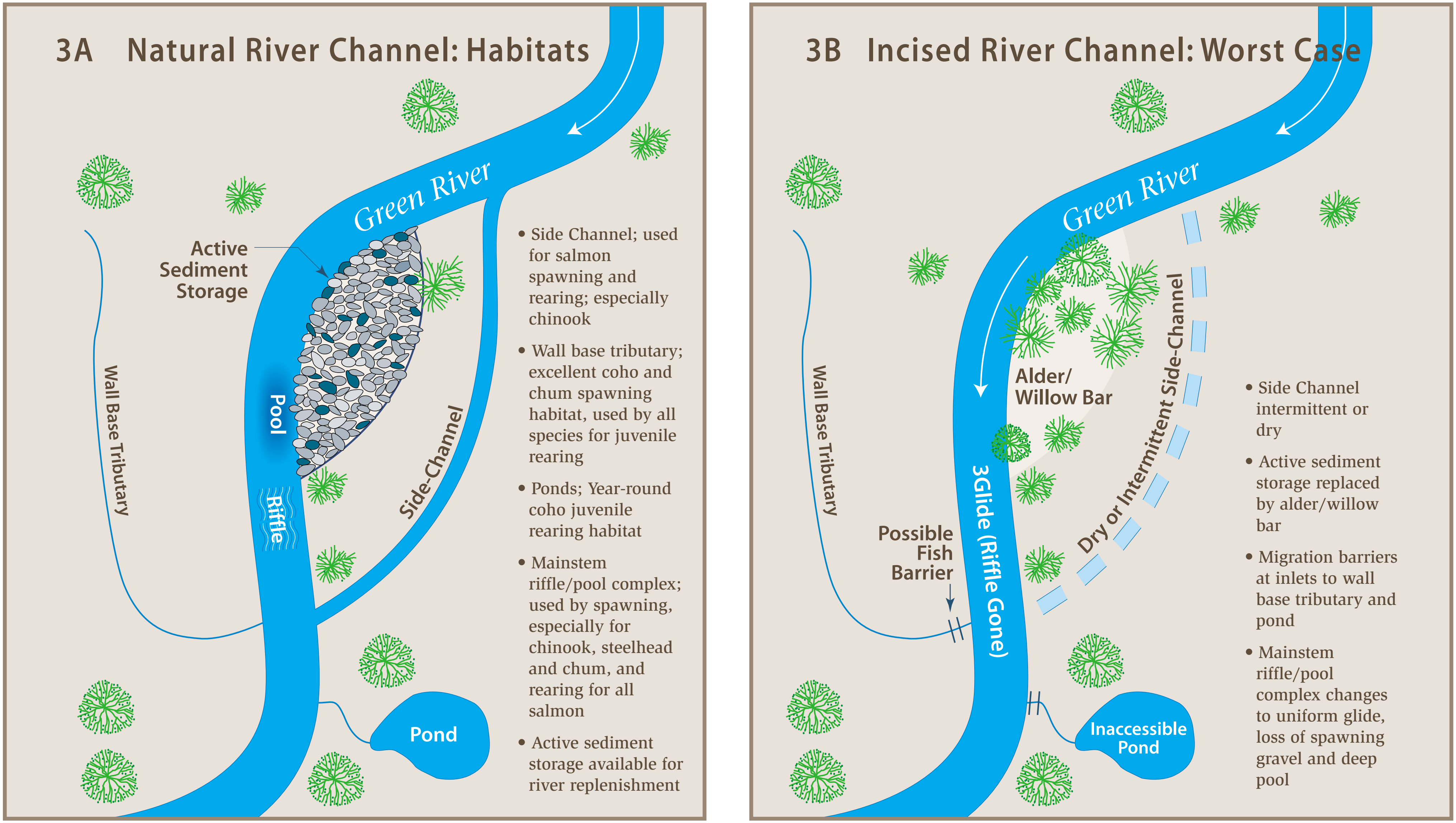


Figure SED-2

Incised Channels with Armoring

King County
Department of Natural Resources

Map produced by: GIS & Visual Communications Unit, WLR
File Name: 0010 Green INCIS sect.ai wgc,lp



Figures SED-3A & SED-3B

Natural and Incised River Channels

Produced by:
King County DNR
Visual Communication/GIS Unit
0010 Green INCIS plan.ai WG,lp

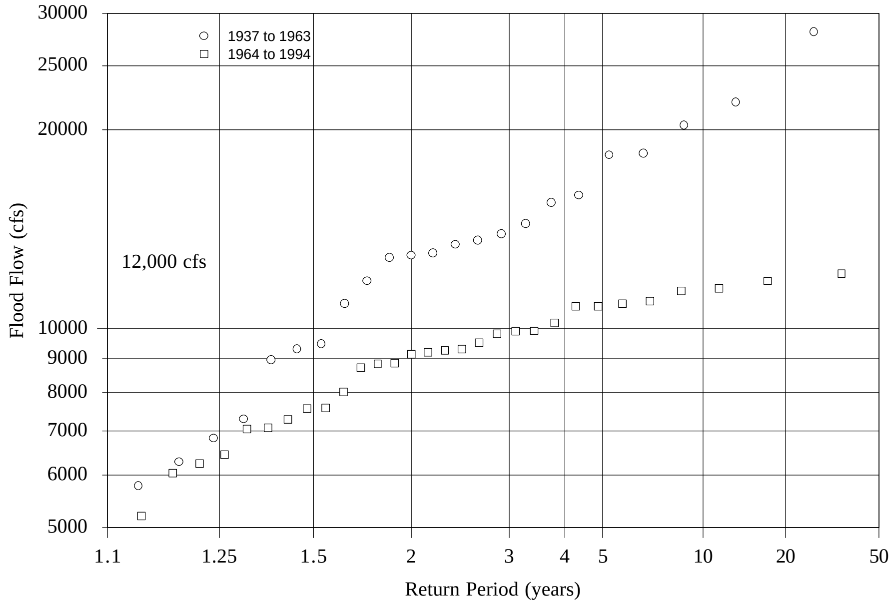


Figure SED-4. Flood-frequency relationships for USGS Gage 12113000 Green River near Auburn, prior to and after construction of Howard Hanson Dam

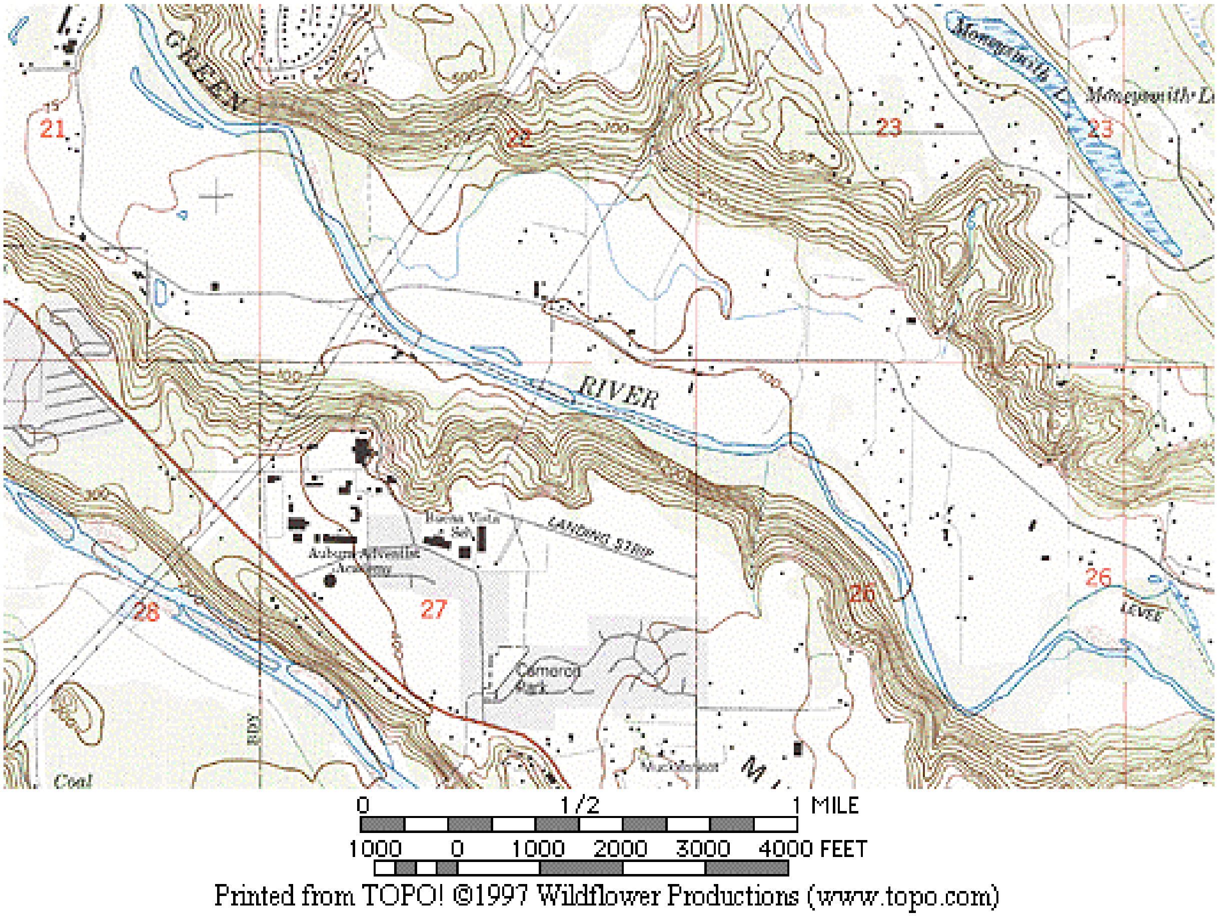


Figure Sed-5. Topographic map of the middle Green River basin illustrating wide alluvial valley and steep valley walls.


Figure Sed-6a. Eroding valley wall composed of unconsolidated glacial sediments near RM 32 on the mainstem Green River.


Figure Sed-6b. Deposit of fine sediment at the base of landslide in mainstem Green River near RM 42.8.

2.3 HYDROMODIFICATION

2.3 HYDROMODIFICATION

EXECUTIVE SUMMARY

The following six (6) types of hydromodifications are known to have affected the Green River:

1. Changes in channel type and the total length of mainstem channel;
2. Bank armoring and artificial channel constraints;
3. Reduced size and frequency of in-stream LWD;
4. Changes in the extent of active gravel bars;
5. Loss of off-channel habitats; and
6. Disrupted floodplain connectivity and function.

For the purposes of evaluating the impact of these hydromodifications, the mainstem Green River basin has been broken into four major sub-watersheds and two major tributary sub-watersheds. Within each sub-watershed, river was subdivided into channel types with similar physical characteristics (e.g. gradient, confinement, sinuosity) that might be expected to respond similarly to disturbances and alteration of channel forming processes. Channel types utilized in the assessment of hydromodifications are described in Table HM-1.

KEY FINDINGS

UPPER GREEN RIVER SUB-WATERSHED (RM 64.5 TO 93)

- High sediment supply has transformed portions of the mainstem Floodplain channel type from pool-riffle to braided morphology. Braided channels experience frequent scour of a depth sufficient to damage or destroy chinook redds and have low pool frequencies, reducing the amount of juvenile rearing and adult holding habitat.

- Inundation by Howard Hanson Reservoir has transformed 4.5 miles of former Floodplain channel type (18% of total in Upper Green River sub-watershed) to periodic Lacustrine habitat and has resulted in the loss of 10,000 linear feet of side channel habitat.

- Armoring of channel banks to protect transportation corridors (roads and railroads) has reduced the complexity and quality of rearing habitat in approximately 6.3 miles (26%) of the remaining Floodplain channel type in the Upper Green River sub-watershed.

- Large woody debris (LWD) loadings in the Upper Green River sub-watershed are currently rated as “not properly functioning” or “fair” to “poor” according to criteria developed by the National Marine Fisheries Service (NMFS) (NMFS 1999) and Washington Department of Natural Resources (DNR) (WFPB 1997). LWD that contributes to “fair” rating is generally small and does not include “key” pieces. The low

LWD frequencies correspond with low pool frequencies, indicating that the lack of LWD in Floodplain channels known to be responsive to LWD has degraded rearing and adult holding habitats required by chinook, coho, and steelhead salmonids.

- Large pieces of LWD (up to 90 feet long) were previously mobilized and transported downstream through Floodplain channels in the Upper Green River sub-watershed. Downstream transport of LWD has been interrupted by HHD since 1964.

MIDDLE GREEN RIVER SUB-WATERSHED (RM 32 TO RM 64.5)

- The total length of Floodplain channel type between RM 58 and RM 61 has declined by approximately 0.5 miles (15%) as a result of road/railroad construction and flood control by HHD. This has resulted in a loss of habitat used by adult chinook and steelhead for spawning, rearing, and adult holding. Coho, cutthroat, and probably chum would use this area for rearing and possibly some spawning.

- Bank armoring to protect transportation corridors has reduced the complexity and rearing habitat value over 1.6 miles (26%) of the Large Contained channel between RM 61 and 64.5. Channel constraints in this segment generally affect only one bank, and have not substantially reduced the ability of this channel to form side or off-channel habitats due to the naturally high confinement (valley width <2 times channel width) of this channel type.

- Construction of levees and revetments to prevent bank erosion and control flood levels has reduced the complexity and rearing habitat value over approximately 5.6 miles (40%) of the Middle Green Floodplain segment between RM 31 and RM 45. Levees and revetments generally affect only one bank in this segment, and thus have not altered the overall channel type.

- The length of channel characterized by a braided morphology between RM 31 and RM 45 declined from 10.4 miles to less than 4 miles from 1936 to 1992 (60% reduction). Reduced area of braided morphology represents an improvement in the stability of spawning habitat, as braided channels typically experience extensive scour on an annual basis.

- The area of active gravel bars in Floodplain segments of the Middle Green River has declined as a result of flood control by Howard Hanson Dam. All 10 acres of formerly active bar surface between RM 56 and RM 61 now support riparian forest communities. Bar area in the Floodplain channel segment between RM 31 and RM 45 declined from 236 to 78 acres (67% reduction) between 1936 and 1992. The loss or stabilization of bar surfaces corresponds with a reduction in shallow marginal habitat and suggests that creation of new side channel habitats and riparian forest stands has been slowed or halted.

- LWD is currently scarce in Floodplain channel types known to be responsive to LWD. No LWD was observed in the Floodplain channel segment between RM 58 and RM 61 on aerial photographs from 1953 and 1987. LWD in the Middle Green Floodplain segment (RM 31 to RM 45) currently averages only 32.6 pieces per mile, even with LWD placement undertaken in recent restoration projects. NMFS criteria for "properly functioning habitat require at least 80 pieces per mile. The lack of LWD corresponds with a scarcity in large pools, which numbered less than 0.12 pools per channel width based on evaluation of air photos from 1992 (Fuerstenberg et al. 1996). The scarcity of LWD and pools indicates that the quality and quantity of mainstem rearing and adult holding habitat has declined in Floodplain channel types.

- The length of side channel habitats in the Floodplain segments of the Middle Green River has declined by over 70 percent as the result of the disconnection of 1.7 miles of side channel between RM 58 and RM 61 from 1953 and 1987, and the loss of 13.8 miles of side channels between RM 31 and RM 45 from 1906 to 1992.

- Decreased flood flows, road and railroad construction, and levees and revetments are believed to have reduced the area of floodplain inundated on a regular basis (by 2-year return interval flood). Available data are insufficient to quantify the magnitude of the reduction.

LOWER GREEN RIVER SUB-WATERSHED (RM 11 – RM 32)

- Six miles of Floodplain channel type and 14 miles of Palustrine channel type have been channelized. Both Palustrine and Floodplain channel types typically have complex planforms and dissipate flood energy by overbank flows. Consequently, channelization has presumably resulted in the loss of almost all mainstem winter rearing habitat and a reduction in the quality of summer rearing and adult holding habitat in these segments.

- All 36 acres of gravel bars (100%) in the former Floodplain channel segment (RM 25 to RM 31) have been lost. These sites formerly provided shallow marginal habitat, increased channel complexity, and sites suitable for colonization by riparian hardwood forests.

GREEN/DUWAMISH ESTUARY (RM 0.0 – RM 11.0)

- Diversion of the White and Cedar/Black Rivers from the Green/Duwamish River has reduced the freshwater inflow to the estuary by about two-thirds and has led to profound changes in the nature of the Duwamish River channel and adjacent floodplain.

- Creation of the Duwamish Waterway resulted in replacement of about 9.3 miles of meandering river with 5.3 miles of straightened channel.

- Approximately 98 percent (2.2 mi^2) of the Duwamish River’s historic floodplain marshes and intertidal mudflats have been replaced with fill, overwater structures, commercial and industrial facilities, and other development.

- A large proportion of the shoreline downstream of RM 5.3 and around Elliott Bay has been armored in some way and much of this shoreline also is altered by the presence of overwater piers and wharves.

- Despite the straightening of the river and loss of intertidal habitat, the Duwamish River and Elliott Bay still have some areas of mudflats that provide important estuarine rearing functions for juvenile salmon.

- Recent habitat management policies and restoration projects, as well implementation of requirements for mitigation for any new losses of habitat, have begun to address the degraded conditions along the Duwamish River.

MAJOR TRIBUTARIES

- The lower 0.3 miles of Newaukum Creek have been dredged and straightened by private landowners.

- Stream cleaning and riparian harvest have reduced the frequency of LWD in the lower 1.4 miles of Newaukum Creek to 0.3 pieces per channel width, a level considered “poor” or “not properly functioning”. Pools are also scarce.

OVERVIEW

Euroamerican settlement of the Puget Sound Region resulted in profound physical changes in river systems and aquatic habitats, as federally or locally funded projects and the activities of private citizens resulted in construction of hydroelectric, flood control and irrigation dams, and diking and dredging projects intended to prevent flood damage and facilitate navigation. Much of the direction for the hydromodification of the Green River was systematized by Col. Howard A. Hanson of the U.S. Army Corps of Engineers in his seminal publication, “More Land for Industry” (Hanson, 1957). This document outlined an incremental scheme for the simplification, channelization and dredging of the Duwamish estuary and for ongoing flood containment for the lower Green River valley through a combined program of massive levee construction and the construction of the Howard A. Hanson Dam.

Prior to 1961, the historic agricultural levee system along the Green River was pursued in an orderly fashion by King County through acquisition of easements, design and construction of a vast, cumbrous array of levees and revetments financed by municipal bonds. This construction effort was carried out by King County crews employing draglines to clear and shape the bank, place riprap and remove LWD from the adjoining channel. This program was active from the early 1960s through the mid- to late 1970s. Rigorous suppression of recolonizing riparian plant communities was also performed in compliance with guidelines for eligibility of local levee systems in the federal levee flood damage rehabilitation administered by the Corps under Public Law (PL) 84-99. County compliance with this federal devegetation requirement was informally suspended in 1989, and formally addressed in the 1993 King County Council adopted King County Flood Hazard Reduction Plan (FHRP) Policies FHR-10 and G-7 (King County, 1993). Project by project consideration of these policies with respect to Green River levee maintenance has resulted in incremental establishment of pioneer seral riparian shrub communities on several levee segments within the lower river, and to the formal disqualification of these same segments from eligibility for federal rehabilitation assistance to repair flood damages.

The general effects of hydromodification on salmonid fishes and their habitats are described below. Subsequent sections provide detailed descriptions of the extent of each type of hydromodifications for each of the five sub-watersheds (Upper Green River, Middle Green River, Lower Green River, Green/Duwamish Estuary and Major Tributaries supporting Chinook).

CHANNEL TYPE

Channel morphology is a useful tool for classifying potential fish habitat in streams and rivers because it: 1) dictates habitat conditions and uses by the various life-history stages of salmonid species (Beechie and Sibley 1997); 2) directly influences the productive capacity of each habitat type (Vannote et al. 1980; Naiman et al. 1992; Paustian et al 1992); and 3) varies in terms of sensitivity and response to changes in inputs of water, wood and sediment from natural or anthropgenic disturbances or from restoration activities (Paustian et al. 1992; Montgomery and Buffington 1993; Rosgen 1994).

Straightening formerly sinuous channels reduces the total length of the river, resulting in an overall loss of habitat and habitat complexity. Construction of levees or revetments and rip-rapping banks prevents lateral channel migration and generally confines flood flows to a single channel that is deeper and narrower and than the natural channel (Dunne and Leopold 1978). The result is greater depths and higher velocity flood flows, which increase the sediment transport capacity (Dunne and Dietrich 1978). Because bank erosion is prevented, the increased sediment transport capacity results in increased scour of the streambed, and the channel may degrade. Increased scour can destroy salmonid redds, and may also result in a loss of suitable spawning gravels in the affected reach (Ligon et al. 1995). Sediment stored in the channel may be routed downstream, reducing the area of gravel bars that form secondary channels and the amount of low velocity marginal habitat. Salmonid fry have a particularly narrow tolerance of depth and velocity extremes; juvenile fishes in the Willamette River avoided velocities greater than 11 cm per second and were not found at depth greater than 30 cm (Li and Shreck 1984). The simplified channel margins offer fewer velocity refugia, thus the quantity of available rearing habitat is reduced.

In contrast, if sediment supplies increase dramatically or reduced flood flows are no longer competent to transport coarse sediment, gravel deposition may increase so much that channels which formerly exhibited a pool-riffle morphology become braided. Braided channels reflect a condition of high sediment supply relative to transport capacity (Montgomery and Buffington 1993). The morphology of braided channels is distinguished by the instability of bars and channels, which may vary from day to day during high flows (Morisawa 1985). The excessive scour and constant shifting of braided channels may destroy salmonids redds, reducing the viability of spawning in such reaches (Schuett-Hames and Schuett-Hames 1984).

BANK ARMORING

The primary function of revetment construction is the mechanical armoring of natural riverbank soils against slumping, sloughing, bank scour and erosive transport of failed bank materials from the affected site. This has as its objective the prevention of channel migration, meander incision, avulsion, braiding and similar natural processes which affect the stability of the adjoining lands and the long-term planform of the river. Revetments are frequently constructed in reaches where complex off-channel habitats are common, cutting those areas off from direct connectivity with mainstem flows. Revetments are also frequently constructed where riparian vegetation and/or instream LWD complexes have been severely modified through land clearing, channel dredging, snagging. These activities commonly result in higher rates of bank erosion that has been historically countered with revetment construction.

Although they also frequently result in armored banks, levees differ from revetments in that they include raised fills placed above the adjoining floodplain at or near the riverbank in order to contain flood flows within a highly channelized conveyance corridor. The function of levees is both to prevent migration or widening of the river channel, as is the case with revetments, and to prevent flooding of lands within the former floodplain, thus levees not only disconnect off-channel habitat from mainstem rivers, they also dramatically alter the hydrologic regime of former floodplain habitats.

Channelization and bank armoring transform formerly heterogeneous banks composed of a variety of substrates to steep banks composed of uniform cobble to boulder-sized material. Natural structural features such as exposed tree roots, LWD, and undercut banks are eliminated. Studies indicate that juvenile salmonid densities and species diversity are generally lower near riprap banks than natural banks (Knudsen and Dilley 1987, Peters et al. 1998). Juvenile chinook and coho, and sub-yearling trout abundance is significantly correlated with the amount of wood cover for both natural and hydromodified banks (Beamer and Henderson 1998; Peters et al. 1998). Sub-yearling chum preferred aquatic plants and cobble, cover types that were most common in natural banks (Beamer and Henderson 1998), while yearling and older steelhead trout densities were unaffected or increased at rip-rap stabilized banks (Peters et al. 1998).

Removal of bank vegetation also reduces shade, overhanging cover, LWD recruitment, and inputs of terrestrial insects and fine particulate organic matter. Reduced shade can result in temperatures that equal or exceed the tolerance of salmonid fishes, particularly in small to medium sized (<20 m) streams at low elevations (Sullivan et al. 1990). Terrestrial insects and fine particulate organic matter are important components of the food chain in riverine ecosystems (Vannote et al. 1980).

LARGE WOODY DEBRIS

Large woody debris is critical component of habitat in rivers and streams of the Pacific Northwest. Large woody debris creates low velocity areas that serve as shelter from swift flood flows, provide cover, and create complex habitat preferred by many species of salmonid for summer and winter rearing (Sedell and Froggatt. 1984; Dolloff 1987; Shirvell 1990; Fransen et al. 1993; Peters et al 1993; Fausch and Northcote 1992; Cedarholm et al. 1997). The introduction of large pieces of woody debris also initiates pool formation (Beechie and Sibley 1997), prompts bar, island and side channel formation (Sedell et al.1984; Abbe and Montgomery 1996), stores sediment (Lisle 1986; Keller 1985) and retains organic matter (Bilby and Likens 1980). The role and function of LWD vary by channel type. In small, steep headwater and tributary channels, LWD traps sediment, dissipates erosive energy, and creates a stepped channel profile, often enhancing the depth and complexity of pools (Sullivan et al.1987; Chin 1989; Nakamura and Swanson 1993). In lower gradient, moderate to intermediate size streams, LWD contributes to channel complexity, bank stabilization, and sediment storage, and is of critical importance for forming pools (Montgomery and Buffington 1993). In large, low gradient rivers, LWD often accumulates in jams that contribute to the formation of off channel habitat and increase the cover and complexity of large pools (Abbe and Montgomery 1996; Benner and Sedell 1997). Abundant LWD helps ensure that cover and habitat suitable for salmonids are available over a wide range of flows. The role of LWD in tidal estuaries is poorly studied but widely assumed to include several of the functions provided in upstream areas. In areas with significant tidal exchange, any given piece of LWD is only in the water for a portion of the tidal cycle, however, so the overall importance may be less than in upstream areas.

In-channel LWD and wood recruitment have been diminished compared to historic levels in many Pacific Northwest rivers, including the Green River, due to logging to the stream bank and clearing of floodplain forests for agriculture (Benner and Sedell 1997; Beechie et al. 1994; Williams et al. 1975). Wood was also removed from the Green River to address concerns about flooding, to facilitate navigation, or up until the late 1970s, to eliminate perceived barriers to upstream migration of salmonids (Pence 1946; Krug 1946; Williams et al. 1975). Reduction in instream LWD has been demonstrated to reduce fish population densities (Bryant 1983; Dolloff 1986; Elliot 1986).

GRAVEL BARS

Increased sediment transport capacity, reduced sediment supply, loss of LWD and reduced flood flows can all result in a reduction in the amount of sediment stored in low gradient reaches as gravel bars. Gravel bars are important for providing complexity in large alluvial channels. In rivers such as the Green, gravel and cobbles suitable for salmon spawning tend to accumulate where topographic complexities lead to areas of reduced boundary shear stress, such as in the lee of islands or in side channels (Ligon et al. 1995). Mid-channel bars develop where obstructions such as key size pieces of LWD deposit (Abbe and Montgomery 1996). Diversion of flow around mid-channel bars further reduces shear stress, eventually leading to the formation of stable islands (Abbe and Montgomery 1996; Leopold et. al. 1964).

Controlling flood flows and interrupting the sediment supply may reduce the amount of spawning gravel and off-channel habitats even in reaches that are unaffected by bank armoring. Side-channel habitats are created by long-term processes of alluvial deposition, channel migration and avulsion (Kellerhals and Church 1989; Morisawa 1985). If peak flows are reduced, particularly in combination with a loss of large woody debris, the channel no longer actively cuts against its banks or avulses, thus eliminating recruitment of coarse sediment from alluvial reaches and preventing the formation of new bars or side channels (Ligon et al. 1995). Loss of gravel bars and prevention of lateral channel migration slows the creation of new riparian zones that replace aging stands of riparian species such as cottonwood or willow, species that typically only germinate on recently exposed soils (Niyama 1990; Strahan 1984; Junk et al. 1989). Given the natural gradient of the Green/Duwamish River system, little gravel typically was carried past the lower Green River sub-watershed into the estuary. Gravel is an uncommon substrate type in most large river estuaries in Puget Sound.

OFF-CHANNEL HABITATS

In addition to a reduction in the quality and quantity of mainstem channel habitat, channelization and bank armoring typically disconnect existing off-channel habitats such as side channels, sloughs and wetlands. Flood control structures and reduced flood flows also prevent the formation of new off-channel habitats (Ligon et al. 1984). Development of river bottomlands for urban or agricultural purposes further eliminates off-channel habitats (Benner and Sedell 1997). Many species of salmonids are attracted to off-channel habitats because the channels are often fed by groundwater and have more consistent flow and temperature regimes than mainstem rivers (Lister and Finnegan 1997). Juvenile coho and chinook often utilize these habitats for overwintering or as refuge from high velocity flood flows (Jeanes and Hilgert 2000; Peterson 1982; Cederholm and Scarlett 1982). Chum salmon frequently spawn and rear in side channels (Salo 1991; Coccoli 1996), and chinook salmon have been observed spawning in the outlets of side channels in the Green River (Malcom 1999).

FLOODPLAIN CONNECTIVITY

Finally, the conversion of lands from historic uses to urban and agricultural development, flood control activities and channelization all contribute to a loss of floodplain function. Forested floodplains reduce the energy of floodflows, protects banks from excessive erosion and capture and store sediment, organic matter and nutrients carried by floodwaters (Benner and Sedell 1997). During periodic inundation of the floodplain water slowly seeps into the soil, recharging shallow alluvial aquifers (Bayley 1995; Junk et al 1989). Water stored in alluvial aquifers and wetlands slowly drains toward the river, sustaining baseflows in off-channel habitats and the mainstem river during periods with little precipitation (Naiman et al. 1992). Without periodic inundation, floodplain streams and off-channel habitats dry up earlier in the season and water temperatures may increase (Gore 1995). Reduced floodplain storage may also lower the growth rate and survival of riparian species, leading to a reduction in riparian corridor width and replacement of historic riparian species with species more tolerant of dryer conditions (Smith 1991).

Methods

Descriptions of the nature and extent of hydromodifications were based on existing data and literature where available. Where data was lacking, a preliminary assessment of hydromodifications was conducted using maps, aerial photographs and GIS analysis. To the extent possible, the following discussion presents quantitative data on the extent and effect of hydromodifications in each sub-watershed. However, some of the information presented is of necessity qualitative or speculative, due to the lack of data on certain types of hydromodifications or in certain sub-watersheds. Methods used to quantify the extent of each type of hydromodification considered in this report are presented below.

CHANNEL TYPE

Channel types in the mainstem Green River were identified based on landform, gradient, confinement and channel planform, using a classification system developed by Paustian et al. (1992). The Paustian channel type criteria were modified to conform with channel segments as defined in the Salmon and Steelhead Habitat Inventory and Assessment Project (SSHIAP) database and Washington State Watershed Analysis Process (NWIFC 1999; WFPB 1997). Table HM-1 lists maps, photos and GIS layers used to stratify channel types and conduct the preliminary assessments.

Current channel types in the mainstem Green River were delineated by measuring gradient and confinement on USGS 1:24,000 scale topographic maps, and refined through review of air photos and watershed analyses channel segment maps, based on the criteria presented in Table HM-2. Information used to delineate general channel types miles (e.g. gradient, confinement, average width, dominate substrate) was evaluated at the reach scale over a distance of miles to tens of miles, and thus does not reflect small-scale variations within any given segment. Channel types delineated at the basin scale may therefore include one or more channel types delineated using the SSHIAP method or defined in existing watershed analyses. For historic conditions, channel type was surmised using vegetation and land survey maps, soils information, and descriptions of the valley by early settlers and surveyors. Table HM-2 provides a brief description of common channel types in the Puget Sound Region, and their importance to various salmonid species and life stages.

The length of each channel type under historical (date of earliest map or photo set) and current (data of most recent map or photo set) conditions was estimated to the nearest tenth of a mile. For the purposes of this analysis, River Mile (RM) 0.0 is located 0.75 miles upstream of the entrance of the west waterway, after Williams (1975). The historical channel length in the Green/Duwamish Estuary, Lower Green, and Middle Green sub-watersheds was estimated using a composite GIS layer of the former channel pattern constructed from data digitized by the USACE (1998) and King County (Perkins 1993). RM 0.0 of the historical channel type corresponds with the mean low water line as mapped by Bortelson et al. (1980)

BANK ARMORING

King County and the EPA each maintain GIS data layers depicting publicly funded levees along the mainstem Green River. The GIS data were used to estimate the length of bank bounded by levees or revetments in each sub-watershed. In addition, the Green River has been constrained in numerous places by roads and railroads throughout WRIA 9. The length of channel affected by transportation corridors was estimated using GIS; roads or railroads that ran parallel to the river and were located within 100 feet of the channel were assumed to have resulted in substantial alteration of channel banks through placement of rip-rap or rock ballast to protect the transportation corridor from erosion during high flows. The percentage of a given reach influenced by levees is based on the channel length rather than the total length of bank affected by levees. The distribution of levees (i.e. on both banks or one bank) is described qualitatively. From RM 11 downstream and around Elliott Bay, shoreline types were documented and mapped by field survey teams during low tides in spring and early summer 1999.

GRAVEL BARS

Reports containing data on the frequency and extent of gravel bars in the mainstem Green River covered only parts of the Upper and Middle Green sub-watersheds (O’Connor 1997; Cupp and Metzler 1996; Fuerstenberg 1996). The historic and current extent of gravel bars in the remaining segments of the mainstem was estimated using historic maps that depicted sand and gravel bars (USACE 1907), or aerial photographs taken during low flow conditions (Table HM-1). The resolution of the available photos varied widely, and information collected for sections of the river where the best available photo scale was 1:12,000 or larger are assumed to represent conservative estimates of in channel sediment storage. Gravel bars were identified as features located within the active channel that had mostly exposed mineral surfaces or that supported only annual vegetation. Only mid-channel and point bars were counted for this assessment; linear stream margins exposed at low flow were not considered gravel bars. Bar surface areas were measured from the photographs using a planimeter.

LARGE WOODY DEBRIS (LWD)

Reports containing information on historic or current LWD were available for parts of the mainstem Green River including RM 77 through RM 93 (Fox 1996; Fox and Watson 1997); RM 34 through RM 47 (Fuerstenberg 1996; King County 1999); RM 5 through RM 11 (Pentec 1999); and for RM 0 to RM 1.4 of Newaukum Creek (Boehm 1999; Malcom 1999). Additional data on LWD in the mainstem Green River was obtained by counting pieces visible on two photo sets obtained from the USACE that covered RM 50 to RM 70 and RM 57 to RM 64.5 (Table HM-1). Large woody debris could not be consistently identified on photographs with a scale of 1:12,000 or larger, thus the preliminary assessment did not cover all channel segments where data was lacking.

OFF-CHANNEL HABITATS

Off-channel habitats associated with the mainstem Green River were assessed using a combination of maps depicting the channel planform (USACE 1907; Perkins 1993; Smith and Associates 1994) and small-scale aerial photographs (Table HM-1). For consistency, only off-channel habitats that had a watercourse depicted on a planform map or that was clearly visible on aerial photos (as water or exposed mineral substrate) were counted for this analysis. The length of each off-channel habitat identified was measured to the nearest tenth of an inch using a map wheel. Very small or older off-channel habitats often cannot be clearly delineated except by field surveys, thus original analysis conducted for this report represent a conservative estimate of the amount of off-channel habitat in the Green River system.

Several reports (Fox 1996; Fox and Watson 1997; Wunderlich and Toal 1992; USACE 1998; Fuerstenberg 1996) present the results of detailed field surveys that identified side channel habitats in the Green River. The results of those surveys were used to supplement original analyses conducted for this report or to describe the current availability of off-channel habitat in areas where maps and photographs of a scale suitable for identification of off-channel habitats were not available.

Off-channel habitats identified for this report were classified as one of four types using a modified version of classification system developed by Peterson and Reid (1984) (Figure HM-1). Secondary channels generally transmit a substantial portion of the mainstem flow and often remain wetted even at the lowest flows. Secondary channels are separated from the mainstem by islands or well-developed mid-channel bars, and are most common in Floodplain channel types. Secondary channels provide shallow, low velocity habitat with varying degrees of cover during low flows, but may be deep and swift during high flows. In addition, Secondary channels are often sites where gravels and cobbles of a size suitable for spawning deposit and generally remain stable (Ligon 1995).

Overflow channels are channels located on the top of point bars. These channels are frequently wetted during moderately high flows (recurrence interval less than one year), and generally do not support perennial vegetation. Multiple overflow channels may form across the top of a point bar as a result of lateral accretion of sediment during high flow events. Although salmon may spawn in overflow channels (Cocolli 1996), these channels frequently become dry between high flow events, desiccating redds and potentially trapping or stranding juvenile salmonids that have sought refuge there.

Wall-base channels are groundwater-fed side-channels typically found at the base of a steep sideslope. Wall-base channels may form as seepage that emerges from the base of the slope converges and flows toward the mainstem or they may represent former river channels that have been abandoned. Wall-base channels typically occupy higher portions of the floodplain or terrace outside the influence of active channel processes (Peterson and Reid 1984). Wall-base channels provide relatively stable flows, a moderated temperature regime and in some cases a complex of channel and ponded habitats. Wall-base channels are known to provide particularly stable rearing environments preferred by some species of salmonids such as coho (Lister and Finnegan 1997; Cederholm and Scarlett 1982).

Meander channels are typically formed when a channel avulsion causes the river to move from its former route. Avulsion may be caused by accumulations of LWD that block the former channel, by meander cutoffs, or by gradual erosion into sloughs or oxbows that have a lower elevation than the existing channel. Recently abandoned meander channels generally have sand or gravel beds and little cover. Over time, wetland or terrestrial riparian vegetation communities become established in meander channels, and the side-channels become sloughs. Meander channels may be fed by ground water, overflow of surface water from the mainstem, or both (USACE 1998). The habitat offered by meander channels varies with their age and connectivity to the mainstem.

Floodplain connectivity Although a thorough analysis of the historic and current extent of the area inundated by floods of various return intervals was beyond the scope of this analysis, changes in floodplain function and connectivity are described qualitatively based on the presence of flood control structures and changes in landuse.

RESULTS

UPPER GREEN RIVER SUB-WATERSHED (RM 64.5 TO RM 93)

CHANNEL TYPE

The upper Green River is comprised of three channel types (Figure HM-2). The upper five miles (RM 88 to RM 93) are a High Gradient Contained channel. Historically, the entire lower 23.5 miles of the mainstem (RM 64.5 to RM 88) were a Floodplain channel type. Since construction of Howard Hanson Dam, the lower 4.5 miles of the former Floodplain channel (RM 64.5 to RM 69) are seasonally inundated and periodically transformed into lacustrine habitat.

High Gradient Contained Channel Segment (RM 88 to RM 93)

High gradient contained channel types in the Upper Green River sub-watershed frequently contain bedrock falls and cascades, thus these channels usually coincide with the upstream extent of anadromous fish use (Fox and Watson 1997). Several reports have identified barriers to anadromous fish in this portion of the mainstem Green River (Williams et al. 1975; USACE 1997). However, because fish passage upstream of RM 61 has been precluded since 1913, it is currently unclear whether the identified features are impassable to anadromous fish (see Chapter 2.5). No persistent disturbances to channel segments corresponding with the High Gradient Contained segment of the upper mainstem Green River were identified in the draft Upper Green/Sunday Watershed Analysis (O’Connor 1997), and the length does not appear to have changed since 1944 (Table HM-3). However, habitat within this channel segment is believed to have been impacted by streamside harvest and sediment delivery by debris torrents originating in tributary streams (Fox and Watson 1997).

Floodplain Channel Segment (RM 69 to RM 88)

Between RM 88 and the confluence with Sunday Creek at RM 84, the valley widens and the gradient of the mainstem Green River decreases to less than 2 percent and develops a meandering planform, becoming a Floodplain channel type. This channel segment contains occasional confined reaches (O’Connor 1997). There is no evidence that the total length of this channel segment has changed substantially as compared to historic conditions. However, significant channel migration has occurred as a result of floods and increased delivery of coarse sediment (O’Connor 1997). The dominant channel morphology is currently plane-bed or braided (O’Connor 1997) rather than the pool-riffle morphology typical of undisturbed Floodplain channels.

The Floodplain channel segment continues downstream of the confluence with Sunday Creek. Historic air photos indicate that the entire mainstem from RM 64.5 to RM 84 was best characterized as a Floodplain channel type, although it includes a number of short reaches of Large Contained channel (Cupp and Metzler 1996). The lower 4.5 miles of this Floodplain channel are now periodically inundated by operation of Howard Hanson Dam, which transforms them into lacustrine habitat when the reservoir is filled. Thus, the total length of Floodplain channel type in the Upper Green River sub-watershed has decreased by about 4.5 miles since 1964 (Table HM-3).

Historically, the Floodplain channel segment in the Upper Green River sub-watershed had “a good pool-riffle balance for this size stream, offering a number of very large, deep pools and long, slow-moving glides. The bottom appears to be quite stable, consisting mainly of clear rubble and gravel material” (Williams et al. 1975). The channel width and extent of gravel bars downstream of the confluence with Sunday Creek and at the junctions of tributaries that experienced debris torrents were observed to change frequently between 1958 and 1992 in response to floods and large storm events (Cupp and Metzler 1996). In 1977, the river shifted north between RM 83 and RM 84, eroding a landing strip located adjacent to the north bank

(Cupp and Metzler 1996). As a result of the increased coarse sediment supply and active channel migration, portions of the Floodplain channel segment upstream of Howard Hanson Reservoir currently lack adequate spawning gravel or experience scour to a depth sufficient to cause redd mortality (Fox 1996). Pools and LWD are generally scarce (Fox 1996; Wunderlich and Toal 1992).

Seasonally Inundated Channel Segment (RM 64.5 to RM 69)

Seasonally inundated habitats are characterized by lake-like habitat conditions when water is stored behind Howard Hanson Dam. Seasonally inundated habitats also differ from historic conditions when the reservoir is drawn down. The dominant effects of seasonal inundation on riverine habitats exposed at low flow have been substantial reductions in vegetative cover, bank stability, pool frequency and quality, and an increase in the amount of fines in riffles (Wunderlich and Toal 1992).

BANK ARMORING

High Gradient Contained Channel Segment (RM 88 – RM 93)

No stream adjacent roads, levees or revetments currently influence habitat in the High Gradient Contained channel segment between RM 88 and RM 93 (Figure HM-3A).

Floodplain Channel Segment (RM 69 to 88)

There are no publicly funded flood control levees or revetments upstream of Howard Hanson Reservoir. However, road and railroad right-of-ways tended to follow the valley bottom along the mainstem Green River and major tributaries, and often resulted in the channel being constrained on at least one side by rip-rap installed to protect transportation corridors from erosion (Figure HM-3A). Under current conditions, bank modifications associated with road or railroad lines affect approximately 20 percent of the channel (about 5 miles) between RM 69 and RM 93 (Table HM-4). Hardened banks generally affect only one bank in this channel segment (Figure HM-4).

The winter floods of 1995-1996 eroded approximately 2,200 feet of river bank adjacent to the Burlington Northern rail line along the Green River between about RM 72 and RM 82. Bank armoring and bank protection measures were implemented where necessary to protect the railline from future erosion. Approximately 1,000 feet of mainstem channel was relocated into an abandoned channel. Fish habitat restoration measures including placement of LWD and riparian tree planting were included in the work (Hadley 2000).

Seasonally Inundated Channel Segment (RM 64.5 to RM 69)

The earliest air photos of the Upper Green River sub-watershed examined for this analysis, taken in 1953, indicate that at that time approximately 1.1 miles of the 4.5 miles of mainstem river between RM 64.5 and RM 69 had artificially armored banks protecting stream adjacent roads or railroads on at least one bank. This segment of the river is now seasonally inundated by Howard Hanson Reservoir, and the banks when exposed are typically composed of easily eroded sand and silt deposited in the impoundment at full pool. It is unknown whether rip-rap installed to protect the former road and railroad right-of-ways influences channel margins in this channel segment when Howard Hanson Reservoir is drawn down.

ACTIVE GRAVEL BARS

High Gradient Contained Channel Segment (RM 88 to RM 93)

Dense riparian vegetation precluded an evaluation of the historic extent of gravel bars in the High Gradient Contained channel segment. However, extensive bars do not typically develop in this high-energy channel type. Recent surveys of several reaches in this channel segment conducted in support of watershed analysis described gravel bar development as “few and forced”, indicating that deposition of otherwise mobile sediments occurs only in the vicinity of stable obstructions (O’Connor 1997).

Floodplain Channel Segment (RM 69 to RM 88)

Watershed Analyses conducted in the Upper Green River sub-watershed describe “abundant medial (complex bars occupying the center of the channel) and forced gravel bars in the upper Green River (Cupp and Metzler 1996). Seventy percent of the alluvial mainstem channel segment surveyed for the Lester Watershed Analysis was occupied by gravel bars (O’Connor 1997); however, the survey reach covered only about 2 miles of the mainstem Green River upstream of HHD, and may not be representative of the entire channel segment. The width and extent of gravel bars has reportedly changed frequently since 1958, in response to debris torrents delivered from tributary streams, and portions of the mainstem are currently described as braided (O’Connor 1996). Spawning habitat is limited due to the coarse nature of the deposited sediment (Fox 1996). Sediment stored in braided channel segments is frequently unstable during peak flows, and scour to a depth capable of destroying redds has been observed in this portion of the channel (Fox 1996; Fox and Watson 1997).

Seasonally Inundated Channel Segment (RM 64.5 to RM 69)

Prior to construction of Howard Hanson Dam, gravel bars were common in the seasonally inundated channel segment; however the total extent of bars was not measured for this assessment. No information is available on the current extent of gravel bars in this channel segment.

LARGE WOODY DEBRIS

High Gradient Contained Channel Segment (RM 88 to 93)

Little data is available on historic LWD frequency in the upper Green River Watershed; however, LWD is presumed to have been more abundant in channels prior to human disturbance.

Upstream of RM 88, the channel width declines to less than 20 meters (Fox and Watson 1997), thus LWD criteria developed for the DNR Watershed Analysis process are the most appropriate means of evaluating LWD conditions (Table HM 5). Wood counts conducted in two reaches covering a total of approximately 660 feet found LWD loadings of 100 and 133 pieces per mile (1.2 to 1.8 pieces per channel width) (Table HM-5) (Fox and Watson 1997). Based on these samples, LWD is currently abundant enough to result in a “fair” habitat condition rating (equivalent to 1-2 pieces per channel width according to WFPB 1997) for the High Gradient Contained channel segment. However, only one of the pieces inventoried was large enough to qualify as a key piece, defined as a log or rootwads with a volume sufficient to ensure it remains independently stable within the channel (NWIFC 1999). Key pieces are important for sediment storage in small steep channels, or as the initiation site for log-jams in larger unconfined channels (Abbe and Montgomery 1996).

Floodplain Channel Segment (RM 69 to RM 88)

Recent surveys of selected portions of the Floodplain channel segment indicate that LWD is generally small, and is scarce in some reaches (Table HM-5). In 1991, only eight pieces of LWD were noted in a survey of 1.26 miles of the mainstem Green River between approximately RM 69 and RM 70.25 (Wunderlich and Toal 1992). Surveys conducted for the Lester and Upper Green/Sunday Watershed Analyses found an average of 284 pieces per mile (4.5 pieces/CW) in eight reaches of the Floodplain segment between RM 77 and RM 88 (Fox 1996; Fox and Watson 1997). Wood loadings in the surveyed reaches varied from 0 to as high as 2,850 pieces per mile in a single reach that contained a large log jam. However, the minimum size of LWD counted for watershed analysis (4 inches diameter by 7 feet in length) is too small to influence habitat in a channel the size of the mainstem Green River. Large Woody Debris frequencies applied in watershed analysis are applicable only to channels less than 20 meters wide (WFPB 1997), thus the frequency of key pieces or LWD criteria presented by NMFS (1999) are deemed more appropriate the mainstem Green River. Only one of the almost 400 pieces of LWD identified was large enough to qualify as a key piece in a channel as large as the mainstem Green River, and the relatively high LWD frequencies did not necessarily correlate with “good” pool frequency ratings, suggesting that much of the in-channel LWD was not functioning to form pools as would be expected under undisturbed conditions (Fox and Watson 1997).

Seasonally Inundated Channel Segment (RM 64.5 to RM 69)

Large woody debris visible in the channel on the 1953 USACE aerial photographs was counted to develop an estimate of the pre-HHD wood loading and transport capability. It is important to note that hydromodification and harvest of streamside timber had influenced the majority of this reach by 1953, thus the estimated historic LWD loading is not representative of undisturbed habitat condition.

Only the largest pieces of LWD can be positively identified through photo interpretation, thus wood counted for this assessment is assumed to meet the minimum size criteria used by NMFS (>24 inches diameter and longer than 50 feet), but probably under-represents qualifying pieces as defined by Watershed Analysis (4 inches in diameter and about 7 feet long) (NMFS 1999; WFPB 1997). In the reach between RM 64.5 and RM 69, a total of 49 individual pieces and three jams composed of 10 or more logs were identified. This translates to a frequency of 19.8 pieces per mile (0.37 pieces per channel width), well below the level required to be rated as properly functioning habitat based on the NMFS (1999) criteria (Table HM-5). At least 13 of the pieces visible on the photos (15%) were more than 90 feet long, and two of these spanned the channel, which had an average width of approximately 100 feet. Eleven of the pieces (12%) had attached rootwads. Most of the wood (79%), including the large pieces, was located along the channel margin or above the low flow channel, suggesting that even very large pieces of LWD are mobile in the mainstem Green River. The remaining 21 percent of the LWD was contributing to summer rearing habitat.

Wood transported downstream from the Floodplain channel segment is currently stranded above the low flow channel as the pool level declines following a flood event, or collects behind Howard Hanson Dam, and is periodically removed from the reservoir and disposed of. Approximately 100 to 150 tons of wood are collected annually (Olson 1999), although the actual amount of wood collected varies widely since LWD inputs and transport are a function of high flows and are episodic in nature. Wood collected from the reservoir is composed of a mixture large logs and small fragments.

OFF-CHANNEL HABITATS

High Gradient Contained Channel Segment (RM 88 to RM 93)

High Gradient Contained channel types typically do not develop extensive off-channel habitats. Reaches sampled within the High Gradient Contained channel type for the Upper Green/Sunday Watershed Analysis contained no off-channel habitats (Fox and Watson 1996).

Floodplain Channel Segment (RM 69 to RM 88)

Little quantitative data is available describing the current or historic extent of off-channel habitats in the Floodplain channel segment, and aerial photographs with a scale appropriate for the identification of off-channel habitats covered only the downstream-most two miles of this channel segment. Two meander channels with a combined length of almost 3,000 linear feet were identified between RM 69 and RM 71 on the 1953 aerial photo coverage (Figure HM-4). Two secondary channels with a total length of 1,245 feet were identified upstream of the current inundation pool between RM 69 and 70.2 in 1991 (Wunderlich and Toal 1992); however, this survey counted only secondary channels that were wetted at the time of the survey. No information on the number or location of historic off-channel habitats or quantitative data on existing off-channel habitat was provided in watershed analyses conducted to date in the upper Green River basin. However, current off-channel habitats were described as "common", and were described as providing the majority of winter rearing habitat based on surveys of portions of the Floodplain channel type between RM 77 and RM 88 (Fox 1996; Fox and Watson 1997).

Seasonally Inundated Channel Segment (RM 64.5 to RM 69)

Approximately 10,000 linear feet of off-channel habitats were identified on the 1953 photos between RM 64.5 and RM 69 (Figure HM-4; Table HM-6). Four of the nine off-channel habitats identified were meander channels, three were secondary channels, and one was an overflow channel that remained wetted at low flow. No wetted side channels were identified between RM 67.8 and RM 69 in surveys conducted by the USFWS in 1991 (Wunderlich and Toal 1992). Seasonal inundation by Howard Hanson Reservoir is believed to have obliterated former off-channel habitats or severely reduced their value as salmonid habitat.

FLOODPLAIN CONNECTIVITY

High Gradient Contained Channel Segment (RM 88 to RM 93)

High gradient contained segments typically do not have floodplains.

Floodplain Channel Segment (RM 69 to 88)

Construction of roads, railroads, residences and other structures within the floodplain of the Upper Green River has disconnected off-channel habitats and reduced the area of the floodplain. However, no information is available on the current or former extent of the floodplain. Changes in the hydrologic regime of the Upper Green River sub-watershed have been minimal compared to other WRIA 9 sub-watersheds (Chapter 2.1) and the primary land-use is commercial forestry, thus changes in floodplain connectivity and function are not believed to have been as pronounced as in other Floodplain segments of the mainstem Green River. Timber harvest and transportation corridors have affected riparian communities in the upper watershed, and these effects are discussed later in the chapter.

Seasonally Inundated Channel Segment (RM 64.5 to RM 69)

Seasonal inundation has profoundly modified the former floodplain in this channel segment. Floodplain surfaces that formerly supported coniferous forest vegetation communities are now barren when exposed, or support only limited communities of annual forbs or inundation tolerant vegetation. The floodplain is typically inundated during the main growing season, and has been buried by deposits of fine sediment.

MIDDLE GREEN RIVER SUB-WATERSHED (RM 32 TO RM 64.5)

CHANNEL TYPE

Channel morphology in the Middle Green sub-watershed is variable, alternating between Floodplain channel types and Large Contained channel types (Figure HM-2). Four distinct channel segments were identified: 1) a Large Contained channel segment just downstream of Howard Hanson Dam (RM 61 – RM 64.5); 2) a three-mile stretch of Floodplain channel type near Palmer (RM 58 to RM 61); 3) the Green River gorge (RM 45 – RM 58), classified as a Large Contained channel type; and 4) a second Floodplain channel type, the Middle Green River between Flaming Geyser Park and the city of Auburn (RM 31 to RM 45).

Large Contained Channel Segment (RM 61 to RM 64.5)

The reach between Tacoma’s Headworks and HHD is a Large Contained channel type, confined between steep hillslopes. In places the channel is further constrained by transportation corridors that are directly adjacent to the river. Aerial photographs examined for this analysis provided no evidence that the channel type or length of this segment changed since at least 1953.
Floodplain Channel Segment (RM 58 to 61)(H4)

Downstream of Tacoma’s Headworks the valley width increases to about 1,000 feet for a distance of three miles, and the channel changes to a Floodplain channel type. Remnant side channels visible of the 1953 aerial photographs provide evidence that this channel segment historically had a more sinuous planform (and thus a lower gradient) than currently exists. Assuming that these former meanders represent the historic channel planform, this channel segment would have been approximately 3.5 miles long, compared to its current length of 3.0 miles (Table HM-3). The reduction in channel length corresponds to an overall loss of aquatic habitat and an increased gradient. In combination with the reduced sediment supply resulting from construction of HHD, these changes are hypothesized to have resulted in a coarsening of the bed and a loss of in-channel sediment storage (Perkins 1999).

Green River Gorge (RM 45 to RM 58)

The Green River gorge begins at approximately RM 58 and extends downstream for about 13 miles, to RM 45. This reach is classified as a Large Contained channel type. The gorge reach is confined between bedrock walls and does not appear to have been directly impacted by development or timber harvest along the river margins. Air photos from 1944 and 1995 examined for this analysis revealed no changes in channel type or length.

Floodplain Channel Segment (RM 32 to RM 45)

Downstream of RM 45, the Green River enters a wide alluvial valley incised through glacial outwash deposits. The channel planform becomes sinuous, and gravel bars and off-channel habitats are common. This section of the river is classified as a Floodplain channel type. While illustrating that the channel planform in this segment has varied considerable over the past 100 years, Perkins (1993) indicated that the overall mainstem length between RM 31 and 45 changed by less than 5 percent between 1906 and 1992; the change actually amounted to an increase of 0.5 miles (Figure HM-5; Table HM3). However, the amount of associated off-channel habitat and complexity of the channel has been greatly reduced since early this century. Extensive gravel bars and a braided morphology formerly characterized an estimated 10.4 miles of this reach in 1892 (Fuerstenberg et al. 1996). In 1994, less than 4 miles of this reach were braided, the length of associated off-channel habitat had decreased substantially and the average channel width between RM 35 and RM 39 had declined by approximately 29 percent (from 277 feet to 195) (Fuerstenberg et al. 1996).

BANK ARMORING

Large Contained Channel Segment (RM 61 to 64.5)

In this segment, the channel is naturally confined between steep hillslopes, thus no levees or revetments have been constructed for flood control purposes. However, the BNSF Railroad and the gravel road to Howard Hanson Dam both parallel the river throughout this reach, and are believed to have altered the natural streambanks through removal of vegetation and placement of rip-rap along approximately 45 percent (1.6 miles) of the channel (Table HM-4). Bank hardening generally affects only one bank of the river in this channel segment.

Floodplain Channel Segment (RM 58 to 61)

No publicly funded levees or revetments have been constructed for flood control purposes in this channel. The BNSF Railroad and the Tacoma Headworks road both run roughly parallel to the river throughout this reach, but impinge upon the channel in only a few locations (Figure HM-3B).

Green River Gorge (RM 45 to 58)

Throughout the Green River gorge, the channel is naturally constrained between steep bedrock walls. There are no roads directly adjacent to the river in this channel segment (Figure HM-3B) and no flood control structures are known to have been constructed in the Green River gorge.

Floodplain Segment (RM 32 to RM 45)

Much of the lower Floodplain segment in the Middle Green River currently has levees or revetments on one or both banks. Armored banks are most common at the downstream end of the Floodplain segment (Figure HM-3B). According to Perkins (1993), 60 percent of the channel between RM 33.8 and RM 37.8 was constrained by levees in 1992; however, less than 30 percent of the banks between RM 37.8 and RM 45 were armored. Overall, approximately 40 percent of this reach has been influenced by bank armoring (Table HM-4). In most cases, levees in the Floodplain segment of the Middle Green River constrain only one side of the river (Figure HM-3B), although in some instances the other side of the river is constrained by steep valley sideslopes.

In recent years, several projects that include setting back or removing levees have been initiated. Large, coniferous logs with rootwads, large woody debris, and riparian revegetation have been incorporated into virtually all levee and revetment repairs on the Green River since 1990 to improve habitat quality. Information gathered on salmonid utilization at one of these sites demonstrates a significant increase in utilization by juvenile and adult salmonids (Peters et al. 1998).

GRAVEL BARS

Large Contained Channel Segment (RM 61-64.5)

The extent of gravel bars in the Large Contained channel segment between RM 61 and 64.5 was assessed using aerial photographs from 1953 and 1987. Sediment stored in in-channel bars large enough to be seen on aerial photos would not be expected in this channel type under natural conditions. No gravel bars were identified within this channel segment on either photo set.

Floodplain Channel Segment (RM 58 – 61)

The extent of gravel bars in the Large Contained channel segment between RM 58 and RM 61 was assessed using aerial photographs from 1953 and 1987. Approximately 7 acres of gravel bars were identified on the 1953 aerial photographs. Three of the four bars present at that time supported some perennial vegetation; however, in no case was more than 50 percent of the bar surface vegetated. By 1987, all of the gravel bars in this channel segment were classified as islands, supporting continuous stands of mature alders. The overall area represented by these islands had increased to 10 acres, largely as the result of the coalescing and stabilization of two formerly active bars near RM 58.5

Green River Gorge (RM 45 – 58)

Gravel bars in the Large Contained channel segment known as the Green River gorge were assessed using aerial photographs from 1944 and 1995. Sediment stored in in-channel bars large enough to be seen on aerial photos would not be expected in this channel type under natural conditions (the scale of the available photos covering the entire gorge segment essentially prevents identification of deposits smaller than about 10,000 ft^2).

No gravel bars were identified within this channel segment on either the 1944 or 1995 photo sets. The 1953 and 1987 photo sets also covered portions of the upstream end of the gorge. Four small gravel bars totaling approximately 3 acres were identified between RM 56 and RM 58 on the 1953 photo set. These bars were still present, but supported continuous perennial vegetation in 1987. The loss of active gravel bar surface is therefore hypothesized to have been influenced more by the reduction in flood flows than by the interruption of the sediment supply caused by construction of Howard Hanson Dam. Although the 1953 photo coverage extended downstream to approximately RM 50, no additional gravel bars were identified, thus in-channel sediment storage within the gorge is believed to have been limited both historically and currently as compared to Floodplain channel types located up and downstream. However, changes in sediment storage are likely to have occurred at the scale of individual habitat units due to the absence of flows greater than 12,000 cfs at Auburn and the reduced supply of sediment and wood from upstream reaches.

Floodplain Channel Segment (RM 32 to 45)

The area of active gravel bars in the Middle Green River system has decreased compared to historic conditions. Fuerstenberg et al. (1996) mapped the change in active gravel bars from 1936 to 1995 in this segment. In 1936, the Floodplain segment of the Middle Green River contained approximately 236 acres of gravel bars; in 1995, the area occupied by gravel bars had decreased to 78 acres, a reduction of almost 70 percent (Fuerstenberg et al. 1996). The lack of floods greater than 12,000 cfs appears to have allowed vegetation to encroach on formerly active bar surfaces. The loss of active gravel bar surfaces may be exacerbated by the reduction in sediment supplied from the Upper Green River sub-watershed, a process that is believed to be contributing to the starvation of in-channel storage areas in the Floodplain reach (Fuerstenberg et al. 1996).

Alluvial rivers may develop a braided morphology in response to large inputs of sediment (Leopold et al. 1964). Braided sections are commonly highly unstable, with the channel location shifting on an annual basis (Knighton 1984). The extensive scour and deposition characteristic of braided reaches may destroy salmonid redds, and prevents the development of new riparian stands that stabilize bars and create rearing habitat for juvenile fish. Portions of the middle Green River Floodplain channel segment have periodically exhibited a braided appearance; braiding was most pronounced in the 1950's and early 1960s following a period of several large floods (Perkins 1993). These areas subsequently became less braided and developed a predominantly single thread channel after flood control by Howard Hanson Dam began in 1962. The total length of braided channel within the middle Green channel segment has generally declined, from approximately 10 miles in 1892 to around 4 miles in 1992 (Fuerstenberg et al. 1996).

LARGE WOODY DEBRIS

Large Contained Channel Segment (RM 61 to 64.5)

No quantitative field data on LWD in this channel segment was located. No LWD was identified within this channel segment on the 1953 or 1987 aerial photographs.

Floodplain Channel Segment (RM 58 to RM 61)

No quantitative field data on LWD in this channel segment was located. No LWD was identified within this channel segment on the 1953 or 1987 aerial photographs.

Green River Gorge (RM 45 to RM 58)

No information on either the current or historic LWD loading was located for the Green River gorge channel segment. No LWD was observed between RM 50 and RM 58 on the 1953 aerial photographs. Since1964, the lack of recruitment from upstream, high stream power, and removal of logs by private individuals concerned about boater safety in the gorge segment are believed to have combined to keep LWD low in this channel segment.

Floodplain Segment (RM 32 to RM 45)

Although there is no quantitative data on historic LWD loading in the Green River prior to Euroamerican settlement, studies of similar large alluvial rivers suggest that LWD and jams were formerly abundant in low gradient Floodplain channels (Sedell and Froggatt 1984; Beechie et al 1994). Agriculture, rural residential development and flood control measures have all contributed to the reduction in recruitment of LWD between RM 45 and RM 31, and will be described in further detail later in the chapter. Interruption of the downstream transport of LWD past HHD has also reduced inputs of LWD to the middle and lower Green River compared to historic levels.

Fuerstenberg et al. (1996) tallied large pieces of LWD visible on 1994 air photos, and identified a total of 376 pieces of wood between RM 34 and RM 45 (Table HM-5). An additional 80 pieces of LWD were placed in the Floodplain segment on the Middle Green River in 1996 as part of the Hamakami levee restoration project (King County 1999). Because the inventory focused on only the largest pieces of wood, and restoration projects typically utilize large logs or rootwads, these data are believed to represent pieces that are roughly comparable to the NMFS minimum size criteria. However, even recent LWD placement has not sufficiently increased the LWD loading in this segment. The current LWD frequency between RM 34 and RM 45 is approximately 27 pieces/mile as compared to the 80 pieces/mile required to be considered “properly functioning” according to NMFS (Table HM-5). Fuerstenberg et al. (1996) identified fewer than 35 pools in the entire Floodplain channel segment (equivalent to a pool frequency of approximately 0.12 pools per channel width. While there are currently no criteria identifying appropriate pool frequencies in large rivers, the lack of LWD and scarcity of pools in a channel type known to be responsive to LWD suggests that the lack of pools may be related to the scarcity of LWD.

OFF-CHANNEL HABITATS

Large Contained Channel Segment (RM 61 to 64.5)

Off-channel habitats in the Large Contained channel segment between RM 61 and 64.5 were assessed using aerial photographs from 1953 and 1987. No off-channel habitats were observed in this channel segment on either the 1953 or 1987 aerial photographs.

Floodplain Channel Segment (RM 58 to 61)

Approximately 12,340 linear feet of off-channel habitats were visible on the 1953 aerial photos in this channel segment (Figure HM-6; Table HM-6). Approximately 75 percent of off-channel habitat identified consisted of two large meander bends. A former meander on the south side of the valley near RM 59 (Signani Slough) was separated from the river by construction of the Tacoma Headworks Road and Burlington Northern Railroad, presumably around 1911. Salmonids apparently were still able to access Signani Slough in 1953. Signani Slough was filled, channelized and disconnected by the USACE during construction of Howard Hanson dam and re-alignment of the Burlington Northern Railroad Line in 1960 and 1961 (USACE 1998). During construction in 1960-61, over 1,000 adult salmon were trapped in the channel (L. Signani, USACE pers. comm., cited in USACE 1998). Another large meander on the north side of the valley at RM 58 (Brunner Slough) appears to have been abandoned when the channel was originally straightened to cut off Signani Slough. The downstream end of Brunner Slough was still connected to the river at low flow in 1953, and an inlet channel that transmitted flow during floods was present at the upstream end.

By 1987, the amount of off-channel habitat in this channel segment had been reduced by 75 percent, to a total of approximately 3,340 linear feet (Table HM-6). Most of the remaining off-channel habitat in this channel segment consists of short secondary channels (Figure HM 7). Signani Slough still contains wetland and pond habitat that was visible on the 1987 photographs. Brunner Slough is believed to have been isolated from the mainstem because of the reduction in peak flows, and possibly channel incision due to decreased sediment supply. (USACE 1998). No inlet was observed during field surveys of this channel segment in 1996 (Madsen unpublished data), although the outlet reportedly becomes connected at moderate to high flows (Nelson 2000). There are currently plans to reconnect both of these former meanders as part of mitigation and restoration activities to be undertaken in conjunction with the USACE's planned Additional Water Storage Project.

Green River Gorge (RM 45 to 58)

Only four off-channel habitats were identified in the Green River gorge segment, representing a total of approximately 1,850 feet of off-channel habitat. One large secondary channel approximately 800 feet long is located near RM 49.5 and was observed on both the 1944 and 1995 aerial photos. Three additional small overflow channels were identified at the upstream end of the gorge, where the river begins to transition into a Floodplain channel type (Figure HM-6). These channels were all secondary channels associated with active gravel bars that could be seen on the 1953 aerial photos. By 1987, the formerly active gravel bars had stabilized and supported dense terrestrial vegetation, thus the overflow channels were virtually impossible to distinguish even on the 1:400 scale photographs from 1987. However, each of these channels was mapped during field surveys conducted in 1996 (USACE 1998), thus they have been included in this data set. The natural confinement of this portion of the river between high bedrock walls effectively prevents formation of large meander or secondary channels in most of this channel segment.

Floodplain Channel Segment (RM 32 to 45)

Off-channel habitats in the Floodplain reaches of the Middle Green River sub-watershed were assessed using maps of historic channel locations constructed by Perkins (1993), air photos from 1992, and recent FEMA floodplain maps (Smith and Associates 1994). Based on the maps contained in Perkins (1993), there were an estimated 93,852 linear feet of off-channel habitats associated with the Floodplain segment of the middle Green River between RM 31 and RM 45 in 1907. This is believed to be a conservative estimate, because small overflow and wall-base channels or older meander channels may not have been depicted on the maps used to create the channel planform maps. By 1994, the amount of available off-channel habitats had dropped to 20,800 linear feet, a reduction of approximately 78 percent. The majority of off-channel habitat lost was meander channels that were disconnected from the mainstem because of levee construction. However, it is also hypothesized that the prevention of flows greater than 12,000 cfs, combined with the reduction in LWD and sediment delivery from upstream reaches could be isolating several formerly active off-channel habitats upstream of RM 40, leaving them perched above current high flow level.

FLOODPLAIN CONNECTIVITY

Large Contained Channel Segment (RM 61 to 64.5)

There is no floodplain associated with the Large Contained channel segment between RM 61 and RM 64.5.

Floodplain Channel Segment (RM 58 to 61)

Based on the previous extent of meanders in this channel segment, construction of the BNSF Railroad and other transportation corridors appears to have reduced the historic meander belt by as much as 50 percent or more in this channel segment. Although no quantitative data is available depicting the pre- and post Howard Hanson Dam floodplains, the reduction in flood flows has also undoubtedly reduced the floodplain area.

Green River Gorge (RM 45 to 58)

There is no floodplain associated with the Large Contained channel segment known as the Green River gorge.

Floodplain Channel Segment (RM 32 to 45)

While no quantitative data are available to assess the impact of such alterations on the Green River, there has been a reduction in the meander belt width, wetland acreage and in the number of active off-channel habitats. Perkins (1993) conducted a study of channel migration hazards associated with the middle Green River, and found that flood control structures have substantially reduced the meander belt width. In the absence of levees and revetments, the meander belt width between RM 31 and RM 45 ranged from 300 to 1,600 feet in width (Perkins 1993). As a result of constraint by levees, revetments, major roads and developments, areas with a high risk of channel migration in the next 100 years currently range from 30 to 560 feet (Perkins 1993). Assuming that the "constrained meander belt width" can be approximated by applying these distance from each bank of the Green River suggests that flood control has reduced the floodplain by an average of 66 percent since the early 1900s. Such changes are believed to have reduced the channel complexity and floodplain recharge, detrimentally impact salmonid habitat.

LOWER GREEN RIVER SUB-WATERSHED (RM 11 TO RM 32)

CHANNEL TYPE

Prior to the diversion of the White River, the Green River downstream of RM 32 was characterized by two channel types (Table HM-3). Sand and gravel bars were common in the reach between RM 25 and RM 32 (USACE 1907), and the channel was classified a Floodplain channel type based on gradient, confinement, substrate and planform, with morphology and habitat conditions similar to those described for the Floodplain segments of the Middle Green River. The lack of detailed topographic maps and photos depicting channel conditions preclude an accurate identification of the exact downstream extent of the Floodplain channel type; however, the 1907 USACE maps suggest the substrate became finer and bars became less common at a location corresponding approximately to existing RM 25, thus that is the reach break utilized for this analysis.

Between RM 11 and 25, the river is believed to have formerly been a Palustrine channel type, based on gradient, confinement, and descriptions of the valley bottom and soils (Dunne and Dietrich 1978; Mullineaux 1970; Pence 1946). Historically, this reach was gently sinuous, slowly migrating across a swampy floodplain (Dunne and Dietrich 1978). By 1907, levees were already present along much of the lower portion of this segment Palustrine channels generally have organic or fine-grained substrate, lack gravel bars, and are associated with extensive off-channel wetland areas (Paustain et al 1992).

By 1994, virtually the entire Palustrine channel segment and most of the former Floodplain segment had been channelized (Perkins 1993). Today, the entire mainstem Green River in the Lower Green River sub-watershed is classified as a channelized river (Figure HM-2). The total length of mainstem channel in this segment has not changed substantially since 1906 (Table HM-3; Figure HM-5).

BANK ARMORING

Levees and revetments are common in the channelized segment between RM 11 and RM 31. Perkins (1993) indicated that levees and revetments were present along 82 percent of the channel between RM 25.3 and RM 31.7 (Figure HM-3C). Virtually all of the former Palustrine channel between RM 11 and RM 25 is currently confined between levees and/or revetments (Fuerstenberg et al 1996). In the Lower Green River sub-watershed, levees typically line both banks of the river (Figure HM-3C).

LARGE WOODY DEBRIS

There are no data on either historic or existing LWD loading in the mainstem Green River within the Lower Green River sub-watershed.

ACTIVE GRAVEL BARS

The change in active gravel bars in the Lower Green River sub-watershed was estimated by comparing the extent of sand and gravel bars depicted on a historic map from 1907 (USACE 1907) to the current extent of active gravel bars visible in the lower Green River on air photos dating from 1995. Approximately 36 acres of active gravel bars were measured between RM 25 and RM 31 on the 1907 USACE map. For the first one half mile downstream of the confluence with the White River (RM 31), deposition of bedload sediments carried by the White River caused the channel to braid, and double in width as compared to the Green River just upstream (Perkins 1993). By 1960, only six of the bars large enough to have been mapped in 1907 remained (Perkins 1993). Extensive levee construction occurred during the 1960s and 1970s, and by 1992, only one bar remained that was large enough to show at the scale of the 1906 map (Perkins 1993). No active bars were detected on 1:12,000 scale aerial photos from 1995. Channelization and the resulting increased sediment transport capacity are the likely cause of the loss of bars in the Floodplain channel segment (Dunne and Dietrich 1978).

No historic maps depicting former sand or gravels bars between RM 11 and RM 25 are available. Due to the nature of the channel type, sand and gravel bars are expected to be less common in this segment (Paustain et al. 1992). No active bars were observed in this segment during the review of the 1995 aerial photographs.

OFF-CHANNEL HABITATS

The amount of historic off-channel habitat in the Lower Green River sub-watershed (RM 11 to RM 25) is unknown, since channelization and flow diversions had already begun to influence these channel segments at the time of the earliest maps. The migration rate of Palustrine channels is generally low, but there are frequently extensive wetlands, sloughs and beaver ponds associated with such channel types (Paustain et al. 1992). These features were not consistently identified on early maps, but early descriptions(Thomas and Thompson 1936) of the upper portions of this reach suggest such features were abundant:

> *"Prior to 1906, the larger portion [of the White River] flowed closely along the north side of the valley for two miles, when it turned sharply to the north. After flowing north for about a mile, during normal runoff it was divided into two or three channels but in flood time it was divided into a multitude of channels. These channels seemed to wander aimlessly over the valley …."*

This portion of the Green River currently supports little or no off-channel habitat (Malcom 1999), with the exception of those associated with small tributary channels.

FLOODPLAIN CONNECTIVITY

The historic extent and duration of flooding was sufficient to maintain an extensive network of valley bottom wetlands along the lower Green River. Early surveys of the Puget Sound Region are quoted as describing “extensive swamps in the valley of the Stuck, the White, and the Duwamish rivers” (Smalley 1990). Early maps showed wetlands and areas marked as “unmerchantable timber” that were most likely forested wetlands (USGS 1894) Prior to flood control activities, the area subjected to overflow between Auburn and the Black River is estimated to have exceeded 16,000 acres (Shapiro and Associates 1990). Natural levees created slight gradients away from the river so that runoff drained toward the outer margins of the valley, then north to the mainstem through a network of small channels. (Pence 1946).

Diversion of the White River, construction of levees and revetments, and operation of HHD have reduced the area subjected to frequent inundation more in the Lower Green River sub-watershed than in any of the other sub-watersheds discussed in this report. Howard Hanson Dam and the levee system provide flood control, but have not fully eliminated backwatering and ponding of water in the lower watershed. Even though peak flood stages have been reduced by dam operation, the prolonged duration of moderately high flows released from reservoir storage together with confinement of these flows by levees actually raised flood stages and related backwater elevations affecting lower valley tributaries for more minor flood events (Levesque 1999).

Following major inundation of the entire eastern portion of the lower Green River valley in 1965, Congress approved Soil Conservation Service (SCS) plans in 1996 to construct 55 miles of drainage channels to alleviate these conditions (Shapiro and Associates 1990). In anticipation of this initiative, the Green River Flood Control Zone District (GRFCZD) was formed in 1960 to sponsor federal implementation of this flood control scheme. In 1972 the GRFCZD sponsored construction of two pump station facilities within the lower Green River by the Soil Conservation Service (SCS) and limited construction of associated channelization projects. While Renton has continued to participate with SCS (renamed Natural Resource Conservation Service in 1997) in these efforts, Kent has pursued its own major modifications to the original plan on its own initiative. The most recent project elements have included construction of the Oaksdale Avenue culvert improvements in Renton and Kent’s conversion of former sewage lagoons to a large scale Mill Creek (Kent) flood storage/wetland habitat/open space complex near RM 19.0 on the Green River. Initial SCS planning on the west side of the Green River has been the topic of extensive restudy resulting in the 1998 Mill Creek (Auburn) Flood Management Plan, which has not yet been implemented.

GREEN/DUWAMISH ESTUARY

CHANNEL TYPE

The large unregulated freshwater outflow of the original Duwamish River (before 1906) built and maintained a large, and likely relatively dynamic estuary in the lower Duwamish valley. This delta was constrained between the hills now occupied by Seattle and West Seattle. Based on early maps, the estuary was characterized by a sinuous main channel and several distributaries. These stream meanders would have been constantly changing as is typical of a low gradient river with substantial periodic sediment-laden flood flows. Because of the influence of the glacially fed White River, the lower estuary would have been subject to high sediment and turbidity levels throughout the summer months, and the turbid freshwater plume would have extended well into Elliott Bay, as it now does in Commencement Bay.

Reduced sediment transport and greatly reduced flood flows and low flows resulting from tributary diversions (Chapter 2.1) by themselves would certainly have greatly reduced the extent of estuarine habitats in the estuary over time. However, beginning as early as 1895, tide flats and saltmarshes along the Duwamish River and the Seattle waterfront were being filled with soil cut from hilly areas to the east and with sediments dredged to create protected harbor areas. These and subsequent actions preempted natural channel changes that might have resulted from the altered hydrology and sediment loading. Filling also created thousands of acres of new uplands along the Duwamish River.

Based on historic maps, Blomberg et al. (1988) determined that the Duwamish Estuary historically included at least three meandering distributary channels, with about 440 acres of deeper (MLLW to approximately –15 ft MLLW) channels downstream of the present location of RM 7. In the early 1900s, the natural estuary was greatly modified by the construction of Harbor Island, the East and West Waterways, and the Duwamish shipping channel. Creation of the waterways resulted in replacement of 9.3 miles of meandering river with the 5.3-mile straightened channel that exists today (measured from the southwestern corner of Harbor Island to the upper turning basin) and the filling of about 2 mi^2 of intertidal area (Blomberg et al. 1988).

To provide flood control and to maintain the channel alignment, dikes or levees were constructed through virtually the entire reach from the confluence of the Black River (RM 112) to the mouth, and banks were hardened with riprap in areas subject to erosion. Commercial, industrial, and residential developments occupy created uplands along both shorelines. Construction of the shipping channel and construction of revetments, levees and dikes focused remaining freshwater flow from the Green River into a single deep channel except for a shallow secondary channel around Kellogg Island and the split waterways around Harbor Island. The ship turning basin at RM 5.3 functions as a settling basin capturing sediments from upstream sources. As a result, the Army Corps of Engineers dredges this basin approximately every three (3) years. Below RM 5.3, the Duwamish River is dredged infrequently (every 10 years or more), to depths ranging from approximately -30 ft MLLW in the lower (Georgetown) reach to -12 ft MLLW in the upper (14th Avenue Bridge) reach, to accommodate commercial navigation (METRO 1989, Harper-Owes 1983). Above the upper turning basin at RM 5.3, the river retains some sinuosity but little of the natural structure and dynamics of a meandering stream.

BANK ARMORING AND OVERWATER STRUCTURES

As noted above, nearly 100 percent of the shorelines of the estuary downstream of RM 11 are modified by dikes, levees, or revetments. From RM 11 to the turning basin (RM 5.3), a 1999 field survey determined that 56 percent of both shorelines had visible riprap armoring and another 3 percent of the shoreline had vertical bulkheads occupying some portion of the intertidal zone (Table HM-7). In many areas, this armoring occupied only the upper intertidal and nearly 60 percent of the shorelines included mud or sand banks and shoals at lower intertidal elevations. Thus, nearly the entire reach has mudbanks and/or shallows on one side or the other. (Figure

HM-8). In the last few years, riprap or revetment repairs needed to protect adjacent properties have included provisions to enhance the habitat values provided. These measures have included placement of boles with attached rootwads projecting from the bank and plantings of riparian vegetation (e.g., willows) along the upper bank. A relatively small proportion of the shoreline in this area is covered by overwater structures, primarily highway or railroad bridges.

Below the turning basin, except in areas that have been actively enhanced or restored, the extent of shoreline armoring is significantly greater than that upstream of the basin.

From RM 5.3 at the turning basin north to RM 0.0 at the southwest corner of Harbor Island, about 65.8percent of the shoreline is riprapped with another 5.3 percent having near vertical bulkheads (Table HM-7). As in the upper reach of the estuary, a substantial portion of the shoreline still has middle to lower intertidal areas that are sand or mudflat. Except where deeper berths have been dredged from the shoreline to the navigation channel, these intertidal sand and mudflats are continuous with the shallow subtidal sand and mud shelf adjacent to the navigation channel.

From the mouth of the estuary (RM 0.0) north to Pier 91, fully 90 percent of the shoreline is riprapped or armored with rubble (Table HM-7); 16.2 percent of the shoreline has vertical bulkheads (some of the shoreline has vertical bulkheads in the upper intertidal zone and riprap in the lower zone). Intertidal sand and mud substrata are found over only about 12.3 percent of the shoreline.

Along much of the industrialized Duwamish Waterway (downstream of about RM 3.5) and along the Seattle waterfront, physically altered shoreline habitats were further modified beginning in the late 1800s by construction of finger piers and marginal wharfs.

In the reach from RM 5.3 to RM 0.0 approximately 15.6 percent of the shoreline is occupied by such structures (Table HM-7). About 12.4 percent of the shoreline also has substantial in-water structures such as floating moorages or extensive pilings.

From the mouth of the estuary (RM 0.0) north to Pier 91, 65.8 percent of the shoreline, including much of the riprapped shore has overwater piers and wharfs. About 14.5 percent of the shoreline also has substantial in-water structures such as floating moorages or extensive pilings.

Until relatively recently, the majority of these structures were constructed of treated wooden piles. Creosote- and metal-treated pilings have the potential to release toxic preservatives into adjacent waters, although the vast majority of releases occurs in the first few weeks of exposure to the aquatic environment (e.g., Weis et al. 1991, Wendt et al. 1995, but see also Bestari et al. 1998). The extent of these overwater structures and the number of treated wood pilings in the estuary and Elliott Bay was probably at its peak in the late 1940s through the 1960s and has declined since. Also, recent agency policies have led to reduced use of treated wood pilings in new construction and in maintenance activity along the river and waterfront.

LARGE WOODY DEBRIS

As noted above, the role off LWD in tidal estuaries is poorly studied but widely assumed to include several of the functions provided in upstream areas. In the upper estuary (e.g., RM 11 to around RM 8) where tidal range is only a few feet, LWD is assumed to function as it does in upstream areas. Lower in the estuary, especially below the Northwind Wier (RM 6.4) where the tidal exchange often exceeds 8 to 10 ft, any given piece of LWD is only in the water for a portion of the tidal cycle, and the overall importance of wood is assumed to be less than in upstream areas.

Woody debris is still removed from the shipping channel between RM 5.3 and RM 0.0 but no formal LWD removal program is in effect above RM 5.3. LWD was inventoried in the reach between RM 11 and RM 5.3 as part of the shoreline habitat survey during May 1999 (Figure HM-8). An average of 9.5 pieces per mile was documented. Some locally generated LWD enters the stream in the form of fallen alders or cottonwoods. A significant number of pieces of LWD were counted in association with bank restoration projects and with shoreline armoring repair projects. The majority of LWD was from relatively large trees and was well weathered. It was thus assumed that much of this wood was from historic upstream sources. The relatively low density of LWD in this reach is probably the result of upstream removal efforts over the last century and by loss of riparian forests in this reach and upstream. Channelization focuses flood flows in a single confined channel and likely reduces the retention of LWD in the area.

ACTIVE GRAVEL BARS

Due to the nature of the channel type and the location in the watershed, gravel bars are expected to be rare in this segment even under natural conditions (Paustain et al. 1992) No historic maps former sand or gravels bars are depicted on early USACE maps (USACE 1907) between RM 11 and RM 0. No gravel bars were identified within this channel segment during May 1999 field surveys. Limited areas of shallow sand bars were scattered between RM 11 and RM 6.

OFF-CHANNEL HABITATS

Only limited areas of off-channel habitat remain in the Duwamish Estuary, primarily in the mouths of small tributary streams and in constructed mitigation or restoration sites. The shallow secondary channel behind Kellogg Island (RM 1.5 to RM 1.0) provides effective off-channel habitat especially during low tide. Across the river and downstream of Kellogg Island (RM 0.8), a drainage ditch near Terminal 105 was rerouted and expanded by the Port of Seattle to create a 0.3-acre tidal slough. At the lower end of the channel west of Kellogg Island the Seaboard Lumber site project is under construction using NRDA settlement funds. When complete, this site will include about 3.5 acres of new intertidal habitat that is partially off-channel. Also in the channel behind Kellogg Island, the Port of Seattle excavated a channel into a small, 0.4-acre, off-channel wetland (the Puget Estuary) at Terminal 107. The site has been planted with wetland plants and the surrounding slopes with upland buffer plants. The Port of Seattle is evaluating the potential for daylighting Puget Creek into this estuary to further improve habitat for anadromous fish.

Farther upstream just north of the 1st Avenue South Bridge, an existing slough or ditch was enlarged and graded to improve access to the river. This project, which was constructed as mitigation for impacts of rebuilding the bridge, included restoration of approximately 1 acre of new aquatic habitat bordered by a large riparian buffer that was created and planted with native vegetation to shield the area from traffic disturbance.

Floodplain Connectivity(H3)

Diking and channelization in the early part of the 20^{th} Century eliminated virtually all the connections between the Duwamish River and its floodplain. Riparian conditions along the Duwamish River are vastly different today from their condition in 1850. In the historic condition, approximately 1,230 acres of freshwater forested wetlands were found along the river (Blomberg et al. 1988). These areas, which were only inundated by flood events, likely included Sitka spruce (*Picea sitchensis*), willow (*Salix* spp.), red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), roses (*Rosa* spp.), and Douglas spirea (*Spirea douglasii*) (Tanner 1991).

Approximately 1,270 acres of tidal marshes occupied areas between +8 ft to +11 ft MLLW (Blomberg 1988). These areas were likely vegetated by bullrush (*Scirpus maritimus* and *S. americanus*) Lyngby's sedge (*Carex lyngbyei*), and sea arrow grass (*Triglochin maritimum*) (Tanner 1991). Vegetation found higher in the marsh probably included tufted hairgrass (*Deschampsia caepitosa*), saltgrass (*Distichlis spicata*), pickleweed (*Salicornia virginica*), Baltic rush (*Juncus balticus*), silverweed (*Potentilla pacifica*), and red fescue (*Festuca rubra*)(Dethier 1990).

Prior to settlement, approximately 1,450 acres of intertidal flats and shallows occupied areas below +6 to +8 MLLW. Although devoid of macrophytes, small patches of eelgrass (*Zostera marina*) or the green alga *Ulva* may have been present (Tanner 1991). The intertidal flats and shallows were concentrated at the mouth of the estuary bordering the south margin of Elliott Bay (Blomberg et al. 1988).

By 1940, filling of low lying areas had virtually eliminated all of the fringing riparian surge plain forested wetland (termed tidal swamps in Blomberg et al. 1988) or isolated it from the river. In addition, Blomberg et al. estimated that 98 percent of the pre-contact tidal marsh, mud flats, and shallows in the floodplain had been eliminated by dredging and filling with most of this loss coming by 1940. The majority of the near-natural estuarine (tidally flooded) habitats that remained were at Kellogg Island, which itself has been altered by disposal of dredged materials (Grette and Salo 1986). Small areas of *Carex*-dominated marsh, generally under 1 acre in size and widely dispersed, and the unvegetated intertidal benches adjacent to the channel or along the river banks, are all that remained. Blomberg et al. (1988) calculated that in 1986 only 45 acres of tidal marshes and mudflats remained.

MAJOR TRIBUTARIES

CHANNEL TYPE

Soos Creek (RM 0.0 to RM 12.0)

Mainstem Soos Creek is characterized by three different channel types (Figure HM-2). The headwaters of Soos Creek originate on a rolling glacial outwash plain. The channel is unconfined, with a gradient of less than 0.1 percent. Stream flows are generally small, with little erosive energy, and the channel is described as alternating between "sections of good gravel and sections of swampy channel splits with mud bottoms" (Williams et al. 1975), characteristic of a Palustrine channel type. At approximately RM 4.75, Soos Creek enters a narrow, steep sided ravine and the channel becomes a Moderate Gradient Mixed Control type, with a gradient of approximately 1.4 percent. Downstream of RM 2, the channel gradient decreases to around 0.5 percent, and Soos Creek becomes a Floodplain channel type that occupies a steep-sided valley.

Newaukum Creek (RM 0.0 to RM 14)

Like Soos Creek, Newaukum Creek was also subdivided into three channel types (Figure HM-2). The headwaters of Newaukum Creek arise in mountainous terrain, and are classified as a High Gradient Contained channel type from RM 14 to RM 9. Between RM 9 and RM 3, Newaukum Creek flows across a low gradient plateau formed by the Osceola Mudflow. The channel is unconfined, with a gradient of about 0.5 percent, and is classified as a Floodplain channel type. At RM 3, Newuakum Creek enters a narrow ravine, and the gradient increases to 2.7 percent (Boehm 1999). The channel is naturally moderately to tightly confined, and is classified as a Moderate Gradient Mixed Control channel type. Unlike Soos Creek, the steep section of Newaukum Creek extends all the way to the confluence with the Green River, with only a short segment of alluvial fan (about 1,500 feet) extending into the Green River valley.

Soos Creek (RM 0.0 to RM 12.0)

The Soos Creek basin plan indicated that "channelization has occurred since the early 1900's in the upper Soos Creek system" (King County 1989). However, no specific information on the extent and location of bank protection structures was located. No levees maintained by King County or the USACE appear in the GIS database.

Newaukum Creek (RM 0.0 to RM 14)

Channelization and bank modifications have altered channel morphology in the short alluvial fan of Newaukum Creek. Between 1984 and 1990, a landowner periodically bulldozed and re-aligned Newaukum Creek between RM 0.1 and RM 0.3, straightening meanders and piling LWD in the old channel to force flows into the newly excavated channel (Boehm 1999). In addition, the riparian zone was cleared and recently riprapped just downstream of RM 0.1 to protect a septic and well system (Boehm 1999). The Moderate Gradient Mixed Control segment of Newaukum Creek (RM 0.3 to RM 4) is essentially unconfined by levees, revetments or riprap (Malcom 1999). No information was located describing current artificial channel constraints upstream of RM 4.0 in Newuakum Creek.

GRAVEL BARS

Soos Creek (RM 0.0 to RM 12.0)

None of the published literature on Soos Creek describing fish habitat and environmental conditions contained information on the extent of gravel bars in mainstem Soos Creek (Williams et al. 1975; Goldstein 1982; King County 1989). Substrate in the Floodplain channel segment was described predominantly gravel (70-80 percent), and "remarkably few areas of problematic erosion or sedimentation were identified" (King County 1989). Aerial photograph coverage of Soos Creek was 1:12,000 scale or larger, and the channel was generally obscured by vegetation, thus no information on either the historic or current extent of gravel bars is available.

Newaukum Creek (RM 0.0 to RM 14)

The lower 400 meters of Newaukum Creek flow across the Floodplain of the lower Green River, forming an alluvial fan composed of cobble and smaller sized sediments. No data on the historic extent or distribution of gravel bars was located. A gravel bar that has built up at the confluence with the Green River currently impairs upstream migration of adult chinook at some flows (Malcom 1999). Information on the existing or historic extent of gravel bars in the remainder of Newaukum Creek is lacking

LARGE WOODY DEBRIS

Soos Creek (RM 0.0 to RM 12.0)

No data or reports describing either historic or current LWD loadings were located for mainstem Soos Creek.

Newaukum Creek (RM 0.0 to RM 14)

There is no quantitative information on the historic abundance of LWD in Newaukum Creek. In the 1950s, LWD was reportedly systematically removed from lower Newaukum Creek to protect a bridge located approximately 1,000 feet upstream of the confluence with the Green River (Boehm 1999).

Separate surveys of lower Newuakum Creek conducted by King County and the MIT both identified low LWD frequencies, although the criteria used to define LWD differed slightly. King County identified a total of 89 pieces of LWD with a minimum diameter of 10 inches and a minimum length of 10 feet, resulting in a LWD frequency of 64 pieces/mile (0.3 pieces/channel width) in the lower 1.4 miles of Newaukum Creek (Boehm 1999). The MIT survey identified 112 pieces of LWD at least 4 inches in diameter and 6.6 feet long, resulting in an LWD frequency of 1.2 pieces per channel width (112 pieces per mile) (Malcom 1999). In each case the low LWD levels correspond with a lack of pools and overwintering habitat (Malcom 1999; Boehm 1999). Boehm (1999) hypothesized that the loss of LWD may have been partly responsible for a change of species composition from predominantly chum and coho to chinook and steelhead.

OFF-CHANNEL HABITATS

Soos Creek (RM 0.0 to RM 12.0)

None of the published literature on Soos Creek describes off-channel habitat either qualitatively or quantitatively (Williams et al. 1975; Goldstein 1982; King County 1989). Available aerial photograph coverage of Soos Creek is 1:12000 scale or larger, and except for the lower reaches, the channel was generally obscured by vegetation, thus no information is currently available to assess either the historic or existing extent or condition of off-channel habitat.

Newaukum Creek (RM 0.0 to RM 14)

There is no available data on the historic frequency of off-channel habitats in Newaukum Creek. Based on channel type, it is expected that off-channel habitats are likely to be present only in the

1,500 foot long reach where the alluvial fan crosses the Green River floodplain or in the Palustrine segment (RM 5 to RM 10) under undisturbed conditions. Off-channel habitats are expected to be rare in the Moderate Gradient Mixed Control segment (RM 0.25 to RM 5) and the High Gradient Contained segment (RM 10 to RM 14) because the confining valley walls effectively limit lateral migration.

Surveys of lower Newaukum Creek conducted in 1998 categorized the area between RM 0 and RM 0.6 as having “few or no backwaters and no off channel ponds” (Malcom 1999) and are assumed to be representative of the entire Moderate Gradient Mixed Control segment. There is no information on the current extent of off-channel habitat available in the Palustrine segment between RM 5 and RM 10.

FLOODPLAIN CONNECTIVITY

Soos Creek (RM 0.0 to RM 12.0)

Only the lower 2.5 miles of Soos Creek downstream of the confluence with Covington Creek have a well-developed floodplain. The channel in this segment is 30 to 40 feet wide (King County 1989) and occupies an alluvial valley that is approximately 500 to 800 feet wide. No information was located describing the current or historic extent of the floodplain in lower Soos Creek, and it is unknown whether bank armoring or disconnection of off-channel habitats have influenced off-channel habitat connectivity. The increased flashiness of the flow regime has most likely increased the frequency at which floodplain surfaces are inundated, but reduced the duration of time that water is present, thus reducing floodplain recharge. Agriculture and rural development are also hypothesized to have impaired floodplain function in portions of this segment, but the extent of these impacts are unknown at this time.

Newaukum Creek (RM 0.0 to RM 14)

Floodplain development is naturally limited in the High and Moderate Gradient Contained channel segment, thus human activities have not substantially altered floodplain connectivity in upper (RM 9 to RM 14) or lower (RM 0 to RM 5) Newaukum Creek. The Floodplain segment of Newaukum Creek (RM 5 to RM 9) is presumably associated with a floodplain that would support inundation tolerant vegetation, contain side and off-channel habitats and serve as a groundwater re-charge zone. The Palustrine channel segment was described as “cutting through pasture and flat farmlands with very little natural growth available to provide shade and protection to the creek” (Williams et al. 1975). Agricultural and rural residential development have continued to influence habitat in the Palustrine segment of Newaukum Creek, and presumably have resulted in altered floodplain function, however no quantitative data on historic or current floodplain connectivity was located.

LIST OF TABLES

Table HM-1. Map and aerial photo sources used to delineate channel types and conduct a preliminary assessment of hydromodifications WRIA 9.

Table HM-2. Description of natural channel types and relative importance to anadromous salmonids (adapted from Paustain et al.1992 using TFW Ambient Monitoring Channel Classification criteria).

Table HM-3. Current and historic channel types of the mainstem Green River, WRIA 9.

Table HM-4. Approximate current extent of artificial and natural constraints on channel mobility along the mainstem Green River in WRIA 9.

Table HM-5. Current LWD loadings of the mainstem Green River, WRIA 9.

Table HM-6. Current and historic length of major off-channel habitats associated with the mainstem Green River, WRIA 9.

Table HM-7. Elliott Bay/Duwamish Estuary habitat/substrate shoreline measurements.

LIST OF FIGURES

Figure HM-1. Side channel classification system applied to the Green River (after Peterson and Reid 1984).

Figure HM-2. Channel types delineated for the mainstem Green River in WRIA 9.

Figure HM-3A, 3B, 3C. Location of artificial channel constraints (levees, revetments, stream adjacent roads in the upper, middle, and lower mainstem Green River.

Figure HM-4. Length and location of off-channel habitats in the upper Green River subwatershed that were inundated by Howard Hanson Dam Reservoir.

Figure HM-5. Channel configuration in the middle and lower Green River circa 1906 and 1992.

Figure HM-6. Historic length and location of off-channel habitats in the Middle Green River.

Figure HM-7. Current length and location of off-channel habitats in the Middle Green River.

Figure HM-8-1, 8-2, 8-3. Location of artificial channel constraints and large woody debris Green-Duwamish River Estuary.

TABLES

Table HM-1. Map and aerial photo sources used to delineate channel types and conduct a preliminary assessment of hydromodifications WRIA 9.			
Current Conditions			
Source	**Date**	**Scale**	**Area Covered**
Draft Upper Green/Sunday Watershed Analysis Channel Segment Map	O'Connor 1997	1:52,800	RM 84-RM 93
Lester Watershed Analysis Channel Segment Map	Cupp and Metzler 1996	1:52,808	RM 76–RM 84
USFS Watershed Analysis Stream Gradients Map	USFS 1996	1:126,720	RM 64.5-RM 93
USGS topographic maps: Renton Auburn Black Diamond Cumberland Eagle Gorge Cougar Mountain Greenwater Nagrom Lester	 1994 1994 1994 1993 1993 1989 1986 1986 1986	1:24,000	RM 0 – RM 93
Aerial photographs	USACE 1987	1:4,800	RM 57-RM 64.5
Aerial photographs	King County 1992	1:7,200	RM 32-RM 45.5
Aerial photographs	DNR 1995	1:12,000	RM 0-RM 93
FEMA floodplain maps	Smith and Associates 1994	1:2,400	RM 34-RM45
Historic Conditions			
Aerial photographs	USACE 1944	1:20,000	RM 0-RM 93
Aerial photographs	USACE 1953	1:7,200	RM 50-RM 70
Map	USACE 1905	1:4800	RM 0-RM 11
Map	USACE 1907	1:4,800	RM 25-RM 35
Map	Bortelson et al. 1980	1:24,000	RM 0 – RM 7
Map	Perkins 1993	1:24,000	RM 25 – RM 45

Table HM-2. Description of natural channel types and relative importance to anadromous salmonids (adapted from Paustain et al. 1992 using TFW Ambient Monitoring Channel Classification criteria).	
Channel Type	**Channel Characteristics and Life-sSage Use**
Estuarine	Intertidal channels that are directly influenced by tidal inundation and saltwater intrusion. These channels are depositional areas with very low stream power. The entire associated estuarine wetland system defines the extent of the riparian zone. Overbank flows are common with significant deposition of fine material on floodplain areas and lateral channel migration during extreme events. Stream bank composition of sand, fine gravel, and silt make this channel type sensitive to bank disturbance and erosion. Large woody debris may provide important habitat features in these channels, however, there is currently little information on natural LWD loadings in this channel type. LWD is provided almost solely from upstream sources, as the dynamic channel planform and extensive associated marsh and wetland habitat generally preclude establishment of mature streamside forests. These channels are always accessible to anadromous salmonids. Very little, if any spawning occurs in this channel type as substrate is generally very fine gravel, sand, silt, clay, and organic material and stream flows are inappropriate as an incubation environment. Adult salmon use this channel type for holding prior to moving into freshwater and as a migration corridor to access upstream spawning areas. Estuarine channels provide young salmon with nursery habitat providing both slow, deep-water areas with high channel complexity, shallow, subtidal refugia and intertidal areas. Additionally, the rich food production of this channel type provides for rapid growth of fry and fingerling. Downstream migrating smolts will reside in these channel types for extended periods using it as a transition area for osmregulation as they move from the freshwater to saltwater environment.
Palustrine	Very low gradient (<1%), unconfined, low velocity channels that typically flow through wetlands or beaver complexes. Stream power is low and high flows frequently over-top the active channel banks, but in-channel depositional features are rare. Riparian area size is highly variable, but may encompass very large wetlands. These channels and the adjacent riparian areas function as sediment and nutrient sinks, and are important buffers against extreme flood flows. Accelerated sediment deposition caused by riparian or upstream disturbance can adversely affect palustrine channel types. Early maps depict nearly all of the land on the Green River floodplain as “cut areas not restocking” suggesting that they had formerly supported timber that would have served as a source of LWD; however, there are also a number of areas classified as “naturally timberless that probably represent frequently inundated lands that are not sufficiently well drained to support timber growth (Shapiro and Associates 1990). Very little, if any spawning occurs in this channel type as substrate is generally very fine gravel, sand, silt, clay, and organic material and stream flows are inappropriate as an incubation environment. This channel type generally consist of deep, off-channel slough areas providing high quality refugia from wintertime high flows. These channels correspond with unconfined Category 1 channels defined using criteria specified in the TFW Ambient Monitoring Stream Segment Identification Module (NWIFC 1999). Palustrine channel types have not been identified in watershed analyses completed to date for the upper Green River basin.
Alluvial Fan	Moderate gradient (2-8 %), depositional channels that occupy the transitional area between steep mountain slopes and valley floodplains. Stream power decreases in the longitudinal direction and deposition results in channels that change course frequently across the body of the fan. High flows are generally not contained within the active channel banks. Channel banks are naturally unstable due to fine textured alluvial bank materials. Riparian vegetation is critical for bank protection and as a source of LWD for bedload retention and sorting and for channel formation. Alluvial fan channels are generally accessible to adult salmon. Spawning areas are generally located in the downstream portions of alluvial fan channels where gradients are lower. Alluvial fan channels are used by chinook, coho, steelhead and bull trout. Overwintering habitat is provided in pools associated with LWD accumulations and near the base of the alluvial fan where the potential for upwelling groundwater to moderate water temperature and inhibit ice formation can occur. Alluvial fan channels are particularly vulnerable to subsurface flows during periods of high sediment supply. These channels generally correspond with unconfined to moderately confined Category 3 and 4 channels defined using criteria specified in the TFW Ambient Monitoring Stream Segment Identification Module (NWIFC 1999). Alluvial fan and incised alluvial fan channels identified in the Lester Watershed analysis (Cupp and Metzler 1996) represent subsets of alluvial fan channels as described here.
Large Contained	Large (>20m bankfull width), low to moderate gradient (1-3%) channels that are moderately to deeply incised within low gradient landforms. High flows are generally contained within the active channel, and stream power is moderate to high, resulting in sporadic and discontinuous depositional features. Bed material is usually dominated by bedrock or boulders. Stream banks in large contained channels are relatively stable compared to alluvial channels due to the high amounts of bedrock and boulder incorporated into them. However, mass wasting of valley side slopes represents an important source of wood and sediment. Although they tend to be less frequent and persist for shorter periods, LWD accumulations can influence on these channels. Large pieces of debris incorporated into the stream bed can have an important function trapping gravel and cobble substrate used for spawning. Smaller or broken pieces of woody debris recruited into this channel type are generally distribute to downstream waters Large contained channels are generally accessible to adult salmonids, however, partial or complete barriers can occur at bedrock knickpoints. Typically these channels contain less suitable spawning area than alluvial channels due to the patchy accumulation of suitable gravel. These channels provide good rearing habitat for juvenile steelhead, and reaches with stable large woody debris and deep-pool habitats may also be used by other species. Large contained channels correspond to confined Category 2 and 3 channels defined using criteria specified in the TFW Ambient Monitoring Stream Segment Identification Module (NWIFC 1999). Large contained channels have been identified as confined mainstem channels in watershed analyses conducted to date in the upper Green River basin (Cupp and Metzler 1996; O’Connor 1997).
Moderate Gradient Mixed Control	Moderate gradient (2-8%) transport dominated channels with moderate stream power. High flows are generally contained within the active channel. Channel banks are frequently composed of boulder or bedrock materials that limit later channel migration and floodplain development. Much of the usable fish habitat in moderate gradient mixed control channels is keyed to large woody debris. For larger channels, where floodplain development has occurred, these channels are highly dependent on riparian vegetation for bank stabilization and LWD recruitment. Large woody debris may significantly influence channel morphology in this channel type including pool/step-pool formation, flow deflection, and gravel storage and sorting. These channel types are generally accessible to adult chinook salmon, but occasionally barriers at bedrock falls do restrict access. Chinook may use the largest and least steep examples of this channel type, however moderate gradient mixed control channels are generally most important for coho, steelhead, bull trout and cutthroat trout. These channels correspond with moderately to highly confined Category 3 and 4 channels defined using criteria specified in the TFW Ambient Monitoring Stream Segment Identification Module (NWIFC 1999). Moderate-gradient mixed control channels have been identified as low to high powered tributaries (O’Connor 1997) and moderate gradient moderate slope or secondary moderate gradient channels channels (Cupp and Metzler 1996) in watershed analyses conducted to date in the upper Green River basin.
High Gradient Contained	Steep, incised channels (>4 percent). Flows are contained within the active channel, and stream power is high, thus sediment is rapidly transported through these channels (Montgomery and Buffington 1993). Wood frequently spans smaller high gradient contained channels, or enters by sliding downslope, and breaks up rapidly (Nakamura and Swanson 1993). However, LWD incorporated into the bed may remain stable for long periods of time if undisturbed by debris torrents, and is important regulating the downstream movement of sediment and dissipating the energy of high flows (Nakamura and Swanson 1993). Associated riparian areas are generally narrow, extending only to the upper stream bank slope break. Steep sideslope areas are sensitive to shallow mass wasting, which provided the majority of sediment recruitment. High gradient contained channels typically supply downstream waters with sediment, large woody debris, nutrients, and aquatic insects. Large (width greater than about 5 meters) high gradient confined channels may be used by steelhead and bull trout, but this channel type generally provides habitat for primarily resident trout. High gradient contained channels correspond to confined Category 4, 5 and 6 channels defined using criteria specified in the TFW Ambient Monitoring Stream Segment Identification Module (NWIFC 1999). High gradient contained channels have been identified as high powered headwater channels (O’Connor 1997) and V-shaped channels (including depositional and moderate to high gradient types) or secondary high gradient channels (Cupp and Metzler 1996) in watershed analyses conducted to date in the upper Green River basin.

Table HM-3. Current and historic channel types of the mainstem Green River, WRIA 9.

Sub-watershed	Reach[1]	Current Channel Type	Current Length (Miles)	Historic Channel Type	Historic Length (Miles)[2]
Green/Duwamish Estuary	RM 0-RM 11	Channelized	11.0	Estuarine	14.9
Lower Green River	RM 11-RM 25	Channelized	14.0	Palustrine	14.0
	RM 25-RM 31	Channelized	6.0	Floodplain	6.0
	RM 31-RM 45	Floodplain	13.8	Floodplain	13.3
Middle Green River	RM 45-RM 58	Large Contained	13.0	Large Contained	13.0
	RM 58-RM 61	Floodplain	3.0	Floodplain	3.5
	RM 61-RM 64.5	Large Contained	3.5	Large Contained	3.5
Upper Green River	RM 64.5-RM 69	Lacustrine (seasonally inundated)	4.5	Floodplain	4.5
	RM 69-RM 88	Floodplain	19	Floodplain	19
	RM 88-RM 93	High Gradient Contained	5	High Gradient Contained	5
Major Tribs					
	RM 0-RM 2.5	Floodplain	2.5	Floodplain	Unknown
Soos Creek	RM 2.5-RM 4.75	Moderate Gradient Mixed Control	2.25	Moderate Gradient Mixed Control	Unknown
	RM 4.75-RM 13	Palustrine	8.25	Palustrine	Unknown
Newaukum Creek	RM 0-RM 3	Moderate Gradient Mixed Control	3.0	Moderate Gradient Mixed Control	Unknown
	RM 3-RM 9	Floodplain	6.0	Floodplain	Unknown
	RM 9-RM 14	High Gradient Contained		High Gradient Contained	Unknown

[1]Reaches are designated using current river miles; RM 0 of current channel is located 0.75 miles upstream of the entrance to the West waterway, after Williams (1975).

[2]Historic channel RM 0.0 located at mean low water line within current West waterway, as depicted by Bortelson et al. (1980). Historic channels in lower and Middle Watershed mapped using GIS layers constructed from USACE 1906 and Perkins 1993.

Table HM-4. Approximate current extent of artificial and natural constraints on channel mobility along the mainstem Green River in WRIA 9.				
Sub-watershed	**Reach**	**Historic Channel Type**	**Levees, Revetments, Rip-rap (% of channel length)**	**Naturally Constrained (% of channel length)**
Green/Duwamish Estuary	RM 0-RM 11	Estuarine	98[1]	0[2]
Lower Green River	RM 11-RM 25	Palustrine	95[3]	0[2]
Middle Green R.	RM 25-RM 31[3]	Floodplain	82[4]	2[4]
	RM 31-RM 45	Floodplain	39[4]	10[4]
	RM 45-RM 58	Large Contained	0[2]	100[2]
	RM 58-RM 61	Floodplain	<5[5]	<5[2]
	RM 61-RM 64.5[4]	Large Contained	45[5]	100[5]
Upper Green River	RM 64.5-RM 69	Floodplain	0[5]	0[2]
	RM 69-RM 88[5]	Floodplain	26[2]	<5[2]
	RM 89-RM 93	High Gradient Contained	0[2]	100%
Major Tribs.				
Soos Creek	RM 0-RM 2.5	Floodplain	Unknown	0%[2]
	RM 2.5-RM 4.75	Moderate Gradient Mixed Control	Unknown	40%[2]
	RM 4.75-RM 13	Palustrine	Unknown	0%[2]
Newaukum Creek	RM 0-RM 3	Moderate Gradient Mixed Control	8%[6]	90%[2]
	RM 3-RM 9	Floodplain	Unknown	0%[2]
	RM 9-RM 14	High Gradient Contained	Unknown	100%[2]

[1]Blomberg et al. 1988.
[2]Based on USGS topographic maps
[3]Fuerstenberg et al. 1996
[4]Perkins 1993; 85 percent of the existing levees and revetments are located between RM 25 and RM 38
[5]Estimated from USACE 1953 and 1987 photos
[6] Boehm 1999

Table HM-5. Current LWD loadings of the mainstem Green River, WRIA 9.					
Sub-watershed	**Reach**	**Naturally recruited (pieces/mi)**	**Placed as part of restoration projects[1] (pieces/mi)**	**Total Loading (pieces/mi) [key pieces/mi]**	**Relevant Standard[2] (pieces/mi)**
Green/Duwamish Estuary	RM 0-RM 11	2.5	3	5.5[3]	80
Lower Green River	RM 11-RM 25	unknown	28.4	unknown	80
	RM 25-RM 31[3]	unknown	7.8	unknown	80
Middle Green River	RM 31-RM 45	28.9	6.2	35.1[4]	80
	RM 45-RM 58	unknown	0	unknown	80
	RM 58-RM 61	unknown	0	unknown	80
	RM 61-RM 64.5	unknown	0	unknown	80
Upper Green River	RM 64.5-RM 69	unknown	0	unknown	80
	RM 69-RM 88	6.4-2,850[5,6]	0	6.4-2,850 [0]	80 [16]
	RM 89-RM 93[7]	100-133	0	100-133 [0-8]	322 [32]
Major Tributaries					
	RM 0-RM 2.5	unknown	unknown	unknown	322
Soos Creek	RM 2.5-RM 4.75	unknown	unknown	unknown	322
	RM 4.75-RM 13	unknown	unknown	unknown	322
Newaukum Creek	RM 0-RM 3	112[8]	0	112 [1.1]	215[9] [22]
	RM 3-RM 9	unknown	unknown	unknown	322
	RM 9-RM 14	unknown	unknown	unknown	322

[1]The number of pieces of LWD input by recent restoration project was obtained from the King County web-site Boaters Page for the Green River, 10/21/99.

[2]For the purposes of this analysis, NMFS standard for "properly functioning" west-side streams of 80 pieces>24 inches diameter and > 50 feet long is used for channels > 20 meters in width (NMFS 1999); Washington Watershed Analysis standard of >2 pieces of LWD greater than 2m in length and 10cm in diameter per channel width for "good" habitat conditions applied for smaller channels (322 pieces/mile for 10 m channel) (WFPB 1997).

[3]Blomberg 1999 (RM 0-RM5); Pentec 1999 (RM 5-RM 12)

[4]Fuerstenberg et al. (1996)

[5]Wunderlich and Toal (1992) RM 69-RM 70.25; Fox (1996). Data from subsamples of two segments totaling 0.6 miles between RM 76 to RM 84; no mention of habitat restoration, so assume all are naturally recruited. Frequency highly variable by reach, ranging from 36 to 236. None of the pieces observed qualified as key pieces.

[6]Fox and Watson (1997); total LWD frequency data from subsample reaches totaling 0.8 miles; no mention of habitat restoration, so assume all are naturally recruited

[7]Fox and Watson 1997; total LWD f frequency data from subsample reaches totaling 0.1 miles; no mention of habitat restoration, so assume all are naturally recruited.

[8]Malcom (1999). Data from RM 0-RM 0.9; no mention of habitat restoration, so assume all are naturally recruited

[9]Average channel width=15 m (Malcom 1999), thus 2 pieces/CW=215 pieces/mile; 0.2 key pieces/CW=22/mile

Table HM-6. Current and historic length of major off-channel habitats associated with the mainstem Green River, WRIA 9.			
Sub-watershed	**Reach**	**Current length (ft)**	**Historic length (ft)**
Green/Duwamish Estuary	RM 0-RM 11	3,500[1]	4,600[2]
Lower Green River	RM 11-RM 25	0[3]	Unknown
	RM 25-RM 31[3]	unknown	unknown
	RM 31-RM 45	20,800 linear ft[4]	93,852 linear feet[5]
Middle Green River	RM 45-RM 58	1,260 linear ft[6]	1,260 linear ft[7]
	RM 58-RM 61	3,340 linear ft[8]	12,340 linear feet[7]
	RM 61-RM 64.5[4]	0	0 linear ft[7]
Upper Green River	RM 64.5-RM 69	0 (inundated by HHD reservoir)	12,940[7]
	RM 69-RM 88[5]	common[9]	unknown
	RM 89-RM 93	0	unknown
Major Tributaries			
	RM 0-RM 2.5	unknown	unknown
Soos Creek	RM 2.5-RM 4.75	unknown	unknown
	RM 4.75-RM 13	unknown	unknown
	RM 0-RM 3	unknown	unknown
Newaukum Creek	RM 3-RM 9	unknown	unknown
	RM 9-RM 14	unknown	unknown

[1]Blomberg 1999
[2]USACE 1906.
[3]Malcom, 1999.
[4]1992 air photos
[5]Perkins 1993.
[6]1995 air photos
[7] USACE 1944 and 1953 air photos.
[8]USACE 1987 air photos
[9]Fox (1996); Fox and Watson (1997)

Table HM- 7. Elliott Bay/Duwamish Estuary habitat/substrate shoreline measurements.

Duwamish Waterway – River Mile 11.0 to River Mile 5.3

Habitat/Substrate	Linear feet	Miles	Percentage of Shoreline (both banks)
Riprap (visible from river)	33,706	6.38	56.0
Bulkhead (near vertical)	1,697	0.32	2.8
Mudbank	29,993	5.68	49.8
Shoal/mudflat (near or below MLLW)	5,342	1.01	8.9
King County levees	13,604	2.58	22.6
Trees*	21,338	4.04	35.4
Shrubs	45,140	8.55	75.0
Grass	3,126	0.59	5.2
LWD (Number per mile)		9.5	

* Includes 33 individual trees each having a 25-ft dripline (total of 850 ft)

Duwamish Waterway – River Mile 5.3 North to Mouth of Duwamish

Habitat/Substrate	Linear feet	Miles	Percentage of Shoreline (both banks)
Riprap (exposed)	40,450	7.66	49.8
Riprap (under dock)	13,000	2.46	16.0
Vertical bulkhead	4,300	0.81	5.3
Exposed sand/mud substrate	45,400	8.60	55.9
Inwater structures (e.g., moorages, extensive piling)	12,300	2.33	15.1
Vegetated shoreline	22,400	4.24	27.6
Rubble shoreline	5,450	1.03	6.7
Overwater structures (e.g., docks and piers)	12,150	2.30	15.3

Elliott Bay – Don Armeni Park to Terminal 91

Habitat/Substrate	Linear feet	Miles	Percentage of Shoreline
Riprap (exposed)	24,850	4.71	35.7
Riprap (under dock)	34,350	6.51	49.3
Vertical bulkhead/concrete sewalls	11,300	2.14	16.2
Exposed sand/mud substrate	11,750	2.23	16.9
Inwater structures (e.g., moorages, extensive piling)	10,250	1.94	14.7
Vegetated shoreline	3,150	0.60	4.5
Rubble shoreline	2,800	0.53	4.0
Overwater structures (e.g., docks and piers)	45,800	8.67	65.8

00105\002\stateofnearsure\table31.xls

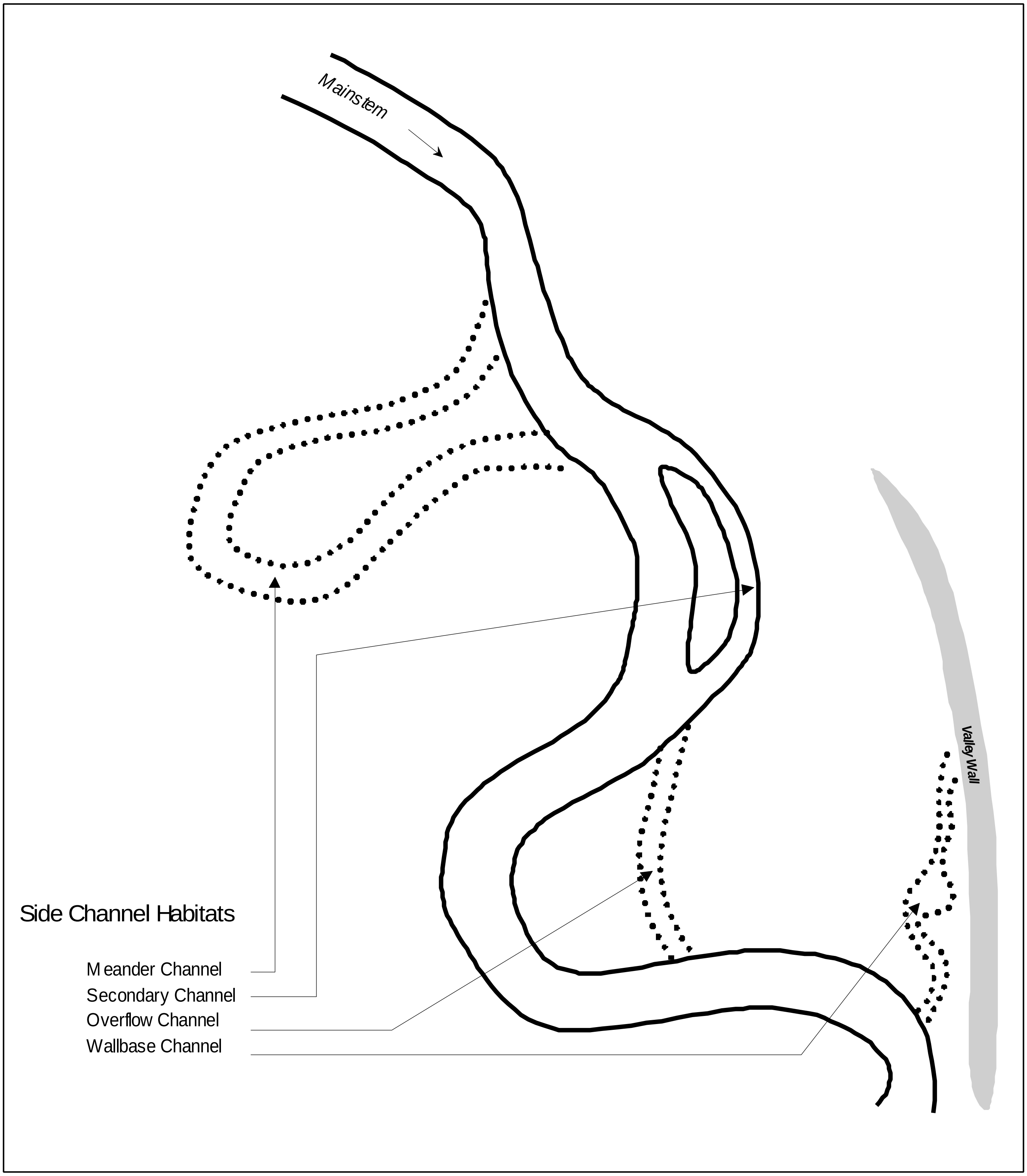


Figure HM-1. Side channel classification system applied to the Green River (after Peterson and Reid 1984).

Figure HM-2

Channel Types

Delineated for the Mainstem Green River in WRIA 9

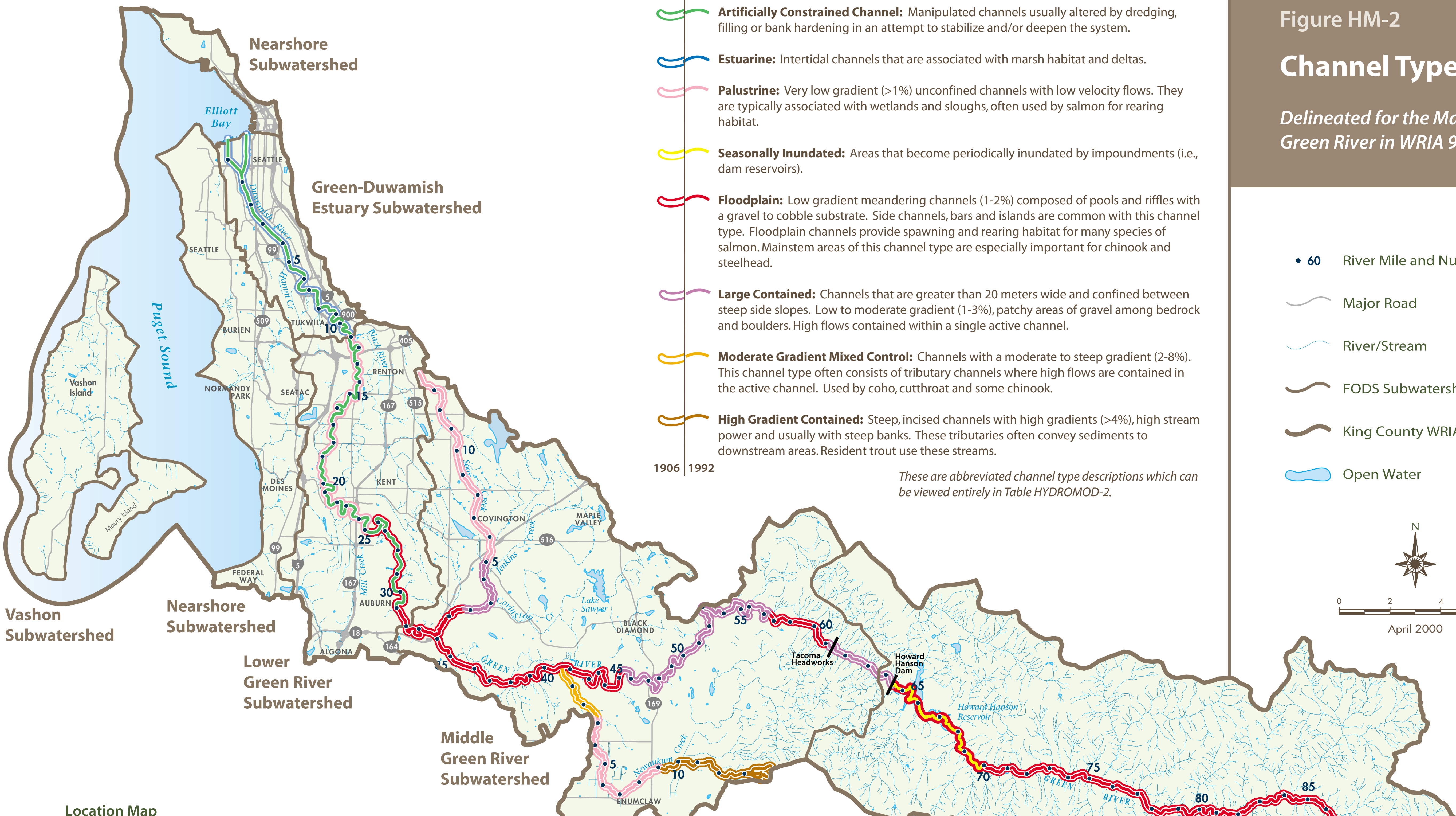
FODS Mainstem Channel Types:

1906 | 1992

- **Artificially Constrained Channel:** Manipulated channels usually altered by dredging, filling or bank hardening in an attempt to stabilize and/or deepen the system.
- **Estuarine:** Intertidal channels that are associated with marsh habitat and deltas.
- **Palustrine:** Very low gradient (>1%) unconfined channels with low velocity flows. They are typically associated with wetlands and sloughs, often used by salmon for rearing habitat.
- **Seasonally Inundated:** Areas that become periodically inundated by impoundments (i.e., dam reservoirs).
- **Floodplain:** Low gradient meandering channels (1-2%) composed of pools and riffles with a gravel to cobble substrate. Side channels, bars and islands are common with this channel type. Floodplain channels provide spawning and rearing habitat for many species of salmon. Mainstem areas of this channel type are especially important for chinook and steelhead.
- **Large Contained:** Channels that are greater than 20 meters wide and confined between steep side slopes. Low to moderate gradient (1-3%), patchy areas of gravel among bedrock and boulders. High flows contained within a single active channel.
- **Moderate Gradient Mixed Control:** Channels with a moderate to steep gradient (2-8%). This channel type often consists of tributary channels where high flows are contained in the active channel. Used by coho, cutthroat and some chinook.
- **High Gradient Contained:** Steep, incised channels with high gradients (>4%), high stream power and usually with steep banks. These tributaries often convey sediments to downstream areas. Resident trout use these streams.

These are abbreviated channel type descriptions which can be viewed entirely in Table HYDROMOD-2.

- • 60 River Mile and Number
- Major Road
- River/Stream
- FODS Subwatershed Boundary
- King County WRIA 9 Boundary
- Open Water



Location Map

Notes:

1. *Basin boundaries were developed for FODS study use only.*
2. *River miles were estimated from "Catalog of Washington Streams and Salmon Utilization", (Williams, et al. 1975).*
3. *Channel types were delineated based on topography, channel gradient, soils and planform characteristics.*

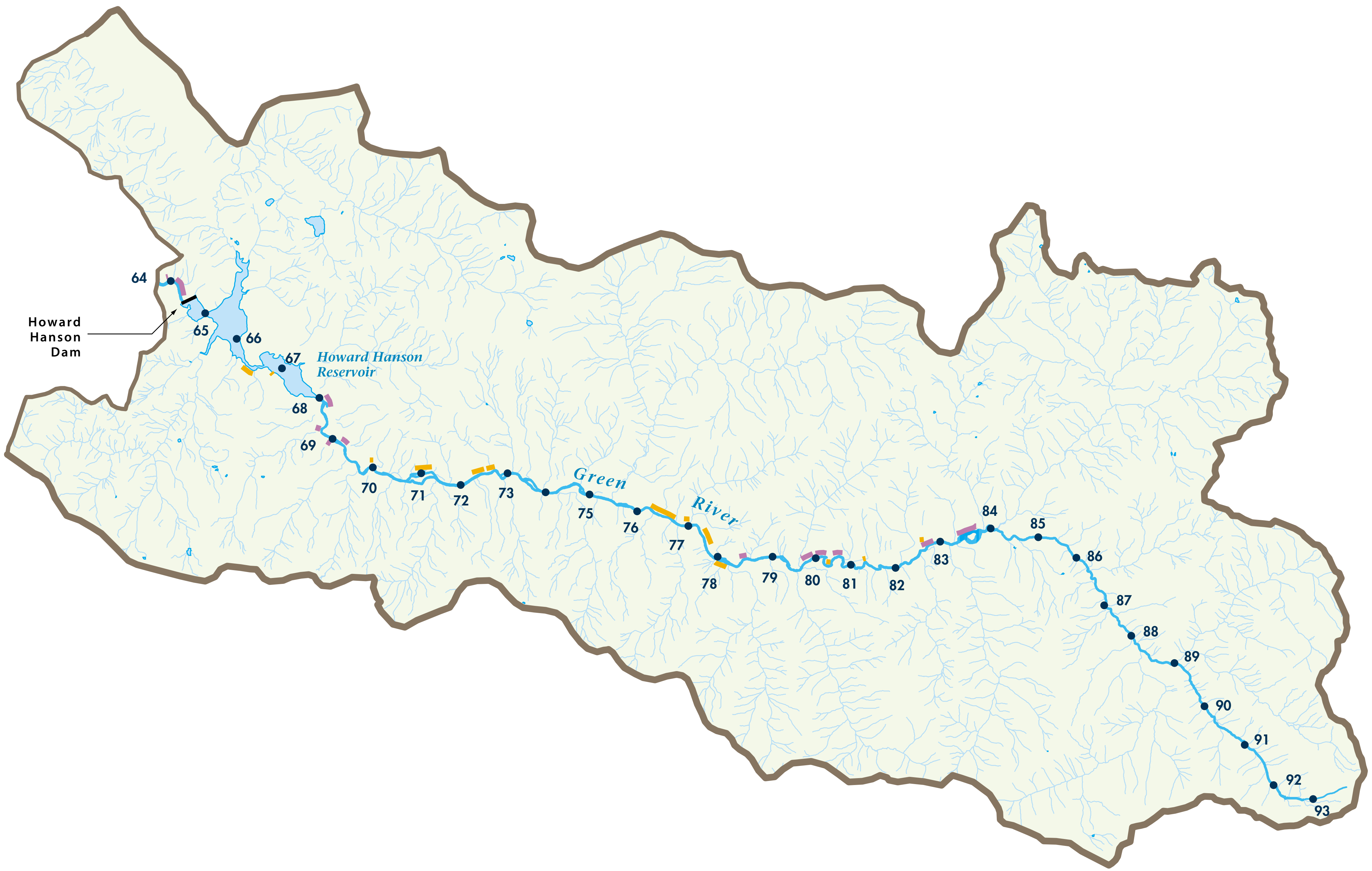
Produced by: GIS/Visual Communications Unit, WLR **File Name:** 0009 W9Recon-ChannelTypes.ai LP

King County Department of Natural Resources

Figure HM-3A

Location of Artificial Channel Constraints

Upper Mainstem Green River



April 2000

Notes:

1. *The basins shown have been defined by R2 as the FODS study area. The "mainstem" is the R2 WRIA 9 Phase I "Mainstem" Analysis definition.*

2. *The road and railroad segments were derived from the best available standard King County road and railroad data by selecting all segments within 100 feet of the bank of the FODS mainstem that werre parallel to the mainstem. Only roads and railroads in the upper watersheds are shown.*

3. *River miles were estimated from "Catalog of Washington Streams and Salmon Utilization", (Williams, et al. 1975).*

King County
Department of Natural Resources

File Name: 0008 W9Recon-UGr.ai LP
Produced by: GIS/Visual Communications Unit, WLR

Figure HM-3B

Location of Artificial Channel Constraints

Middle Mainstem Green River

- 60 River Mile and Number
- Major Road
- River/Stream
- Levees and Revetments
- Stream Adjacent Parallel Road Segments
- Stream Adjacent Parallel Railroad Segments
- Subbasin Boundary
- FODS Subwatershed Boundary
- WRIA 9 Boundary
- Open Water

N

0 2 4 Miles

April 2000

King County
Department of Natural Resources

Produced by: GIS/Visual Communication Unit, WLR
File Name: 0008 W9Recon-MGr.ai LP

Notes:

1. The basins shown have been defined by R2 as the FODS study area. The "mainstem" is the R2 WRIA 9 Phase I "Mainstem" Analysis definition.

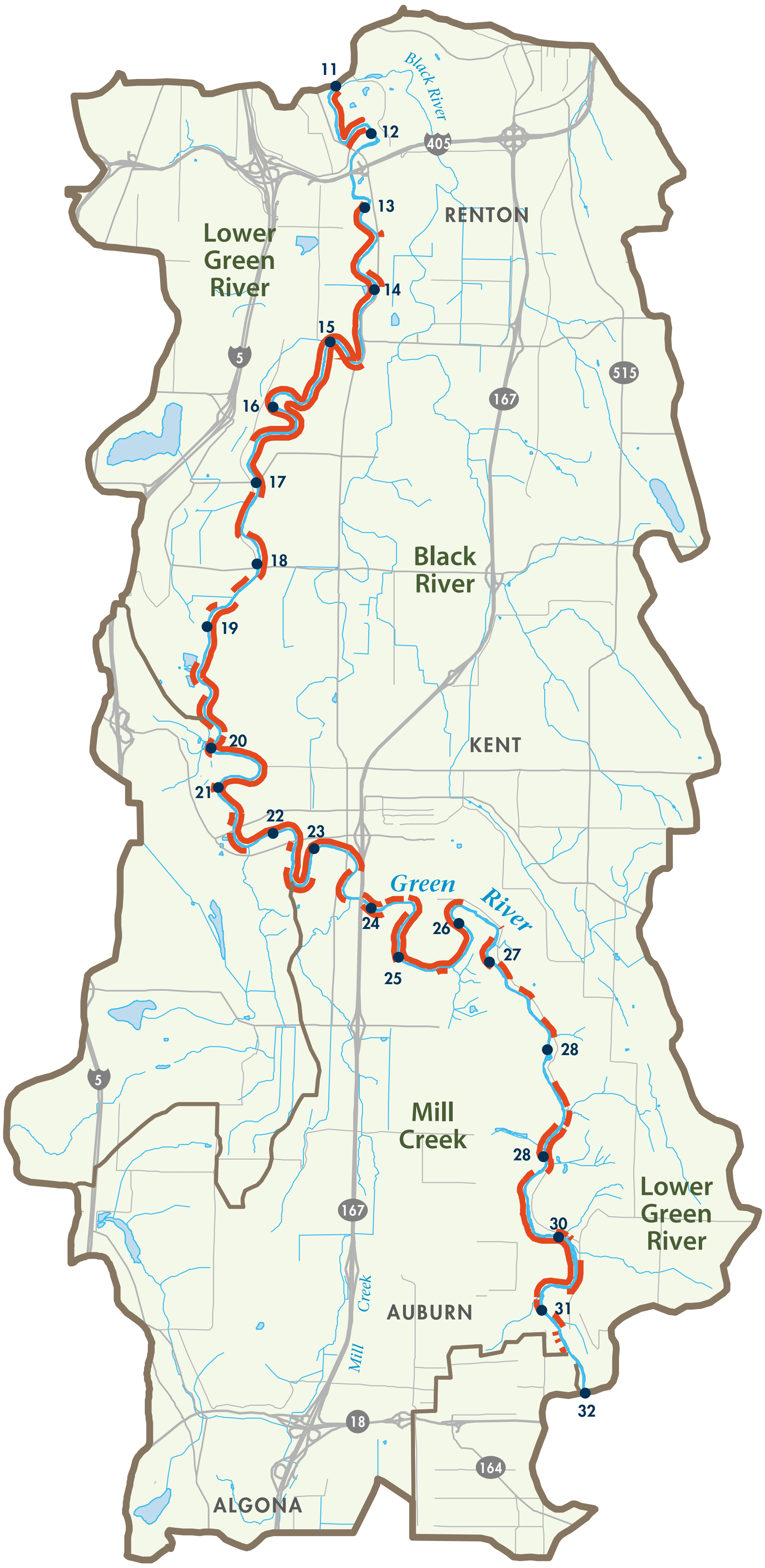
2. The road and railroad segments were derived from the best available standard King County road and railroad data by selecting all segments within 100 feet of the bank of the FODS mainstem that were parallel to the mainstem. Only roads and railroads in the upper watersheds are shown.

3. River miles were estimated from "Catalog of Washington Streams and Salmon Utilization", (Williams, et al. 1975).

Notes:

1. *The basins shown have been defined by R2 as the FODS study area. The "mainstem" is the R2 WRIA 9 Phase I "Mainstem" Analysis definition.*

2. *River miles were estimated from "Catalog of Washington Streams and Salmon Utilization", (Williams, et al. 1975).*



28 River Mile and Number

Levees & Revetments

FODS Subwatershed Boundary

Subbasin Boundary

Major Road

River

Open Water

N

0 1 2

April 2000

Map produced by: GIS & Visual Communications Unit, WLR
File Name: 0008 W9Recon-LGr4.ai LP

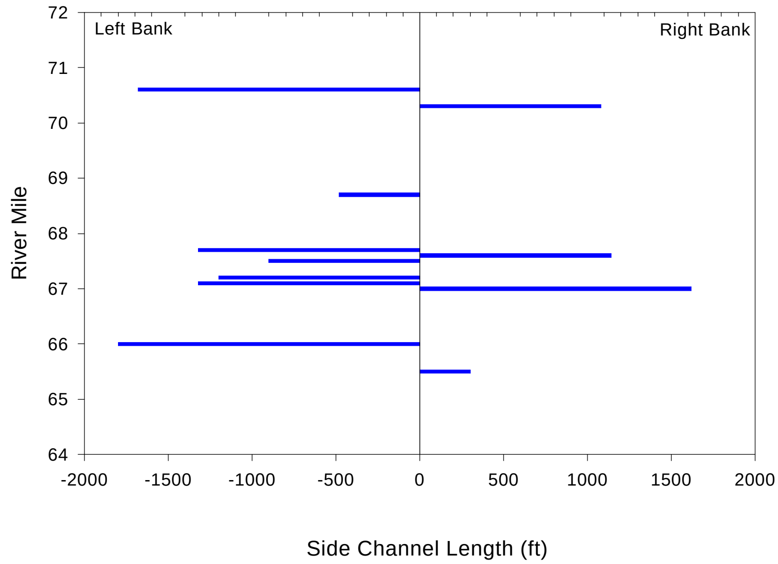
King County
Department of Natural Resources

Figure HM-3C

Location of Artificial Channel Constraints

Lower Mainstem Green River

Figure HM-4. **Side channels in the Upper Green River Subwatershed, RM 64.5 to RM 70 in 1953, prior to inundation by Howard Hanson Reservoir.**



Notes:

1. The basins shown have been defined by R2 as the FODS study area. The "mainstem" is the R2 WRIA 9 Phase I "Mainstem" Analysis definition.

2. River miles were estimated from "Catalog of Washington Streams and Salmon Utilization", (Williams, et al. 1975).

3. Green/Duwamish historical river course is based on U.S. Army Corps of Engineers data and historical paper maps digitized by Ken Zweig, King County Department of Natural Resources, Water and Land Resources Division. Historical data is circa 1906. Current channel data is from the Washington State Department of Ecology.

4. No data on historical channel position is available upstream of river mile 45.

- 4 River Mile and Number
- Basin Boundary
- Subwatershed Boundary
- WRIA 9 Boundary
- Major Road
- Open Water
- Current FODS Green/Duwamish Mainstem
- Historical (circa 1906) Green/Duwamish Mainstem
- Historical Meander Scars

N

0 2 4 Miles

April 2000

Map produced by: GIS & Visual Communications Unit, WLR
File Name: 0008 W9Recon-HistChannel.ai LP

KING COUNTY
Department of Natural Resources

Figure HM-5

Channel Configuration Circa 1906 and 1992

Middle and Lower Green River

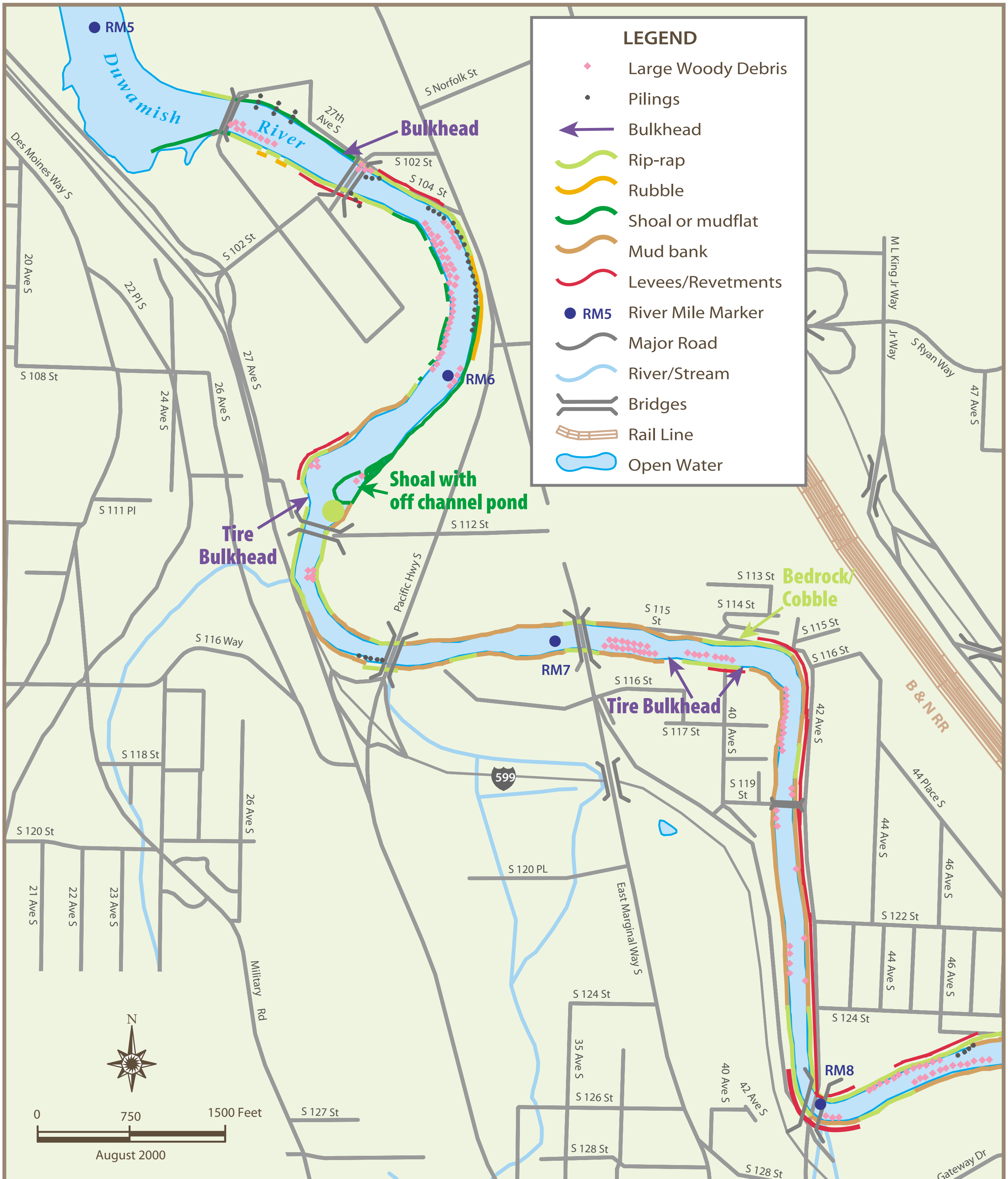


Figure HM-8-1

Artificial Channel Constraints and Large Woody Debris

Green-Duwamish River Estuary - Map 1 of 3

King County Department of Natural Resources

Map produced by: GIS & Visual Communications Unit, WLR
File Name: 0009 W9Recon-Est1.ai

Figure HM-6. Historic length and location of side channels in the Middle Green River Subwatershed, Side channels between RM 31 and RM 45 were identified using maps of the historic channel planform in 1907 from Perkins (1993). Side channels between RM 45 and RM 64.5 were identified using aerial photos from 1944 and 1953.

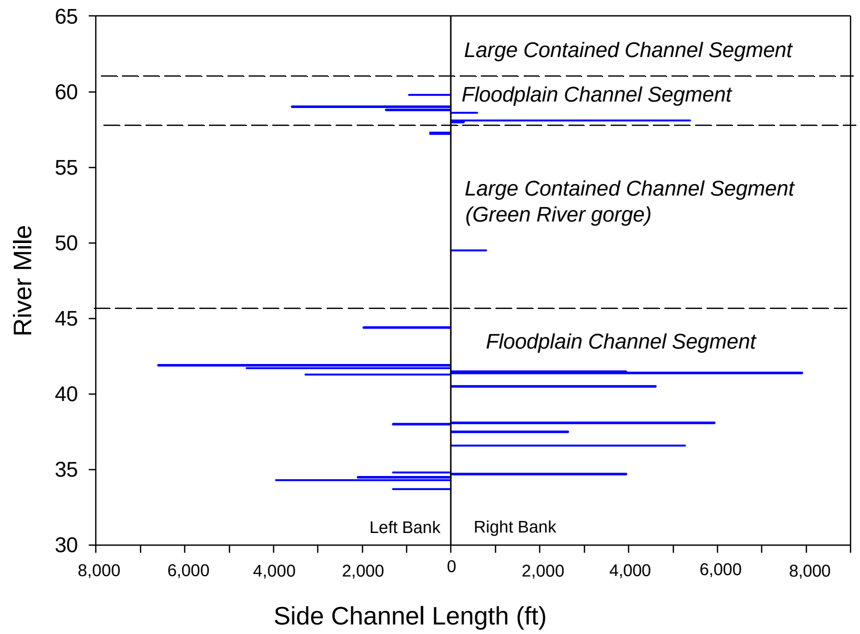
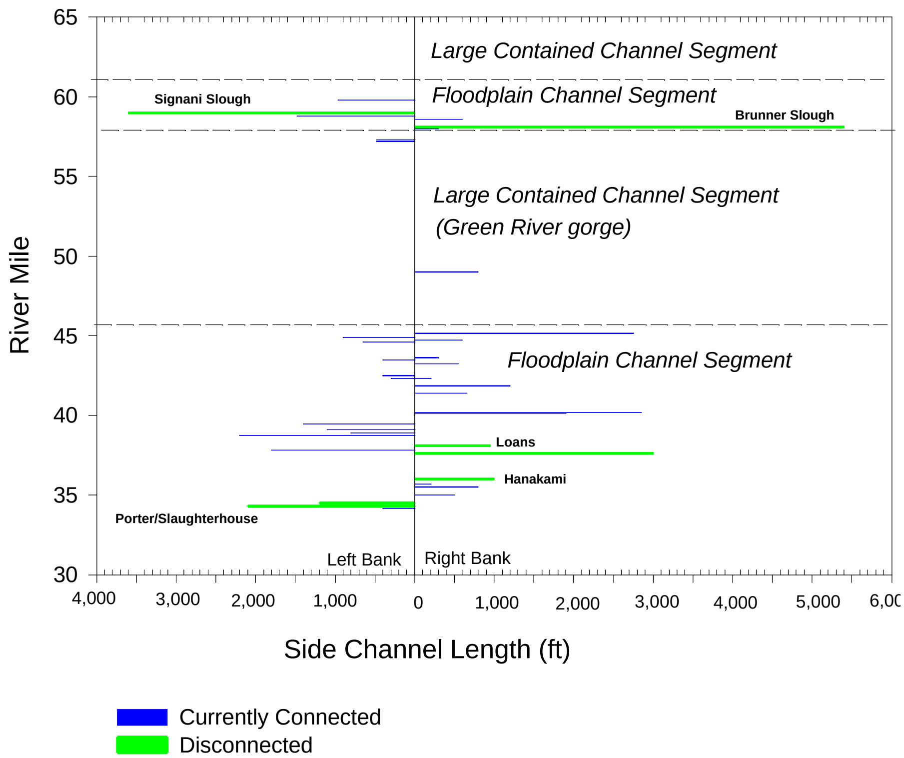


Figure HM-7. **Side channels in the Middle Green River Subwatershed, Side channels between RM 31 and RM 45 were identified using aerial photos from 1992 and detailed floodplain maps (Smith and Associates 1994). Side channels in the Green River gorge were identified using aerial photos from 1995. Side channels between RM 58 and RM 64.5 were identified using aerial photos from 1987.**



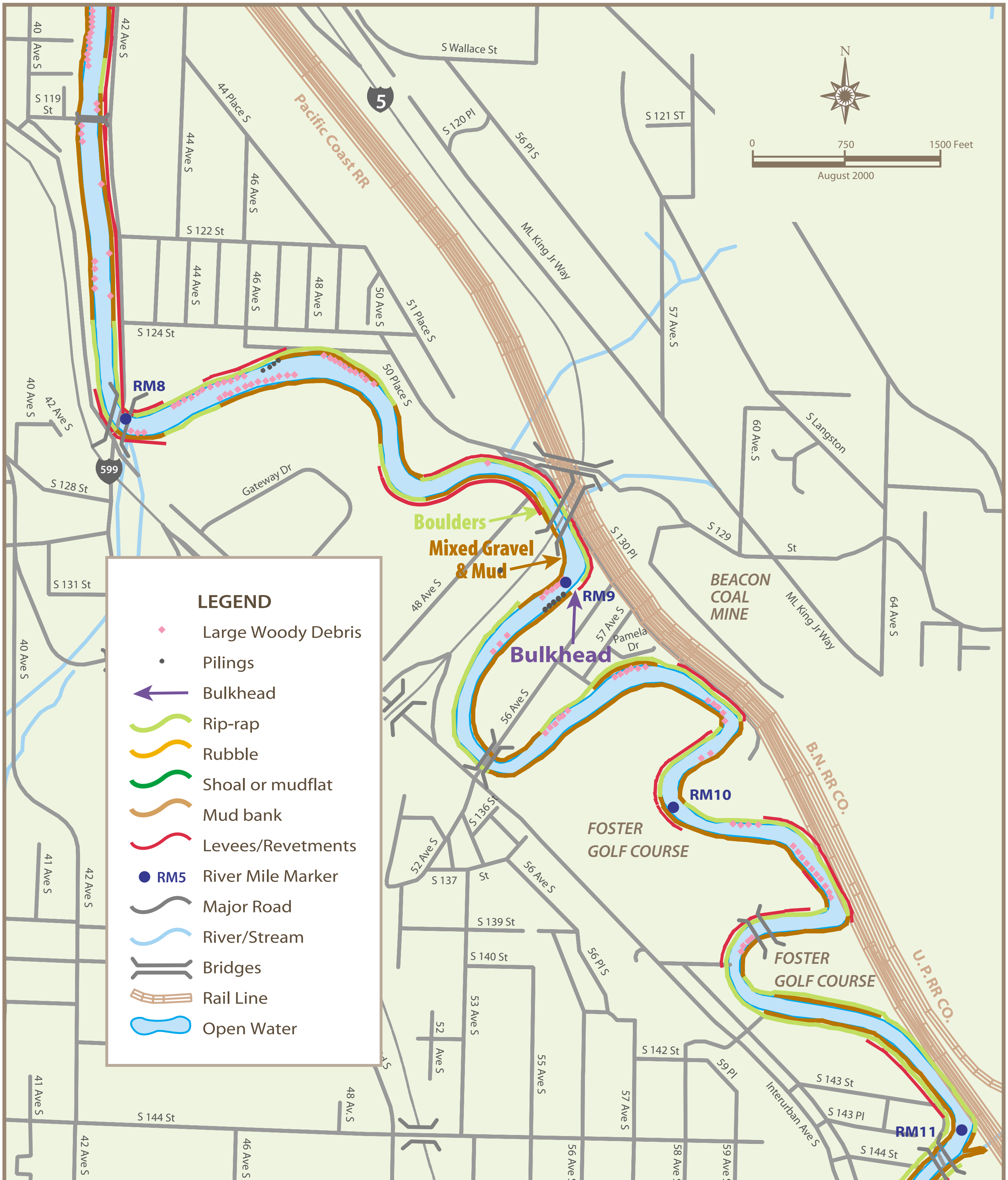


Figure HM-8-2
Artificial Channel Constraints and Large Woody Debris
Green-Duwamish River Estuary - Map 2 of 3

King County
Department of Natural Resources

Map produced by: GIS & Visual Communications Unit, WLR
File Name: 0009 W9Recon-Est2.ai

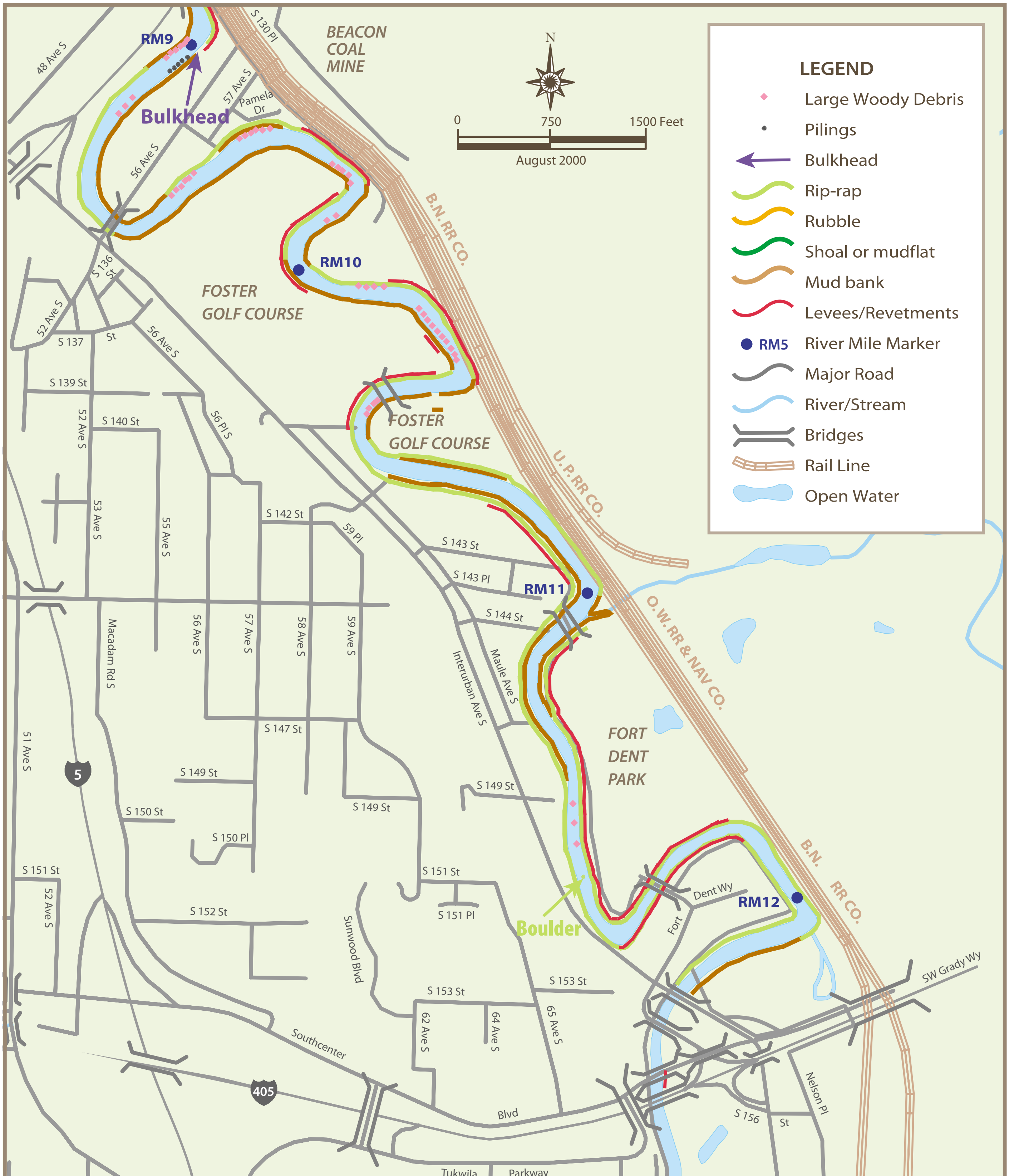


Figure HM-8-3

Artificial Channel Constraints and Large Woody Debris

Green-Duwamish River Estuary - Map 3 of 3

King County
Department of Natural Resources

Map produced by: GIS & Visual Communications Unit, WLR
File Name: 0009 W9Recon-LGr3.ai

2.4 RIPARIAN CONDITION

2.4 RIPARIAN CONDITION

EXECUTIVE SUMMARY

This chapter assesses the current condition of important riparian functions along the mainstem Green/Duwamish River, including:

- Bank stabilization;
- Supply of organic matter and nutrients;
- Shade;
- Large woody debris recruitment;
- Filtration of sediment;
- Channel migration zones; and
- Microclimate.

Current riparian condition was assessed based on vegetation type, size, and density, generally corresponding with the methodologies recommended by the Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) and the Washington Forest Practices Board Manual (WFPB 1997). Existing data were utilized where possible. In areas where no existing riparian data were located, an original assessment was conducted specifically for this report. Criteria used to evaluate each individual riparian function for this report were developed from a number of recent, comprehensive reviews of riparian function (Wenger 1999; Knutsen and Naef 1997; FEMAT 1993; Castelle et al. 1994; Johnson and Rhyba 1992). In addition, the length of river with an "intact" riparian zone and the length of channel bordered by vegetation similar to the potential natural community was estimated. For the purposes of this report, an "intact" riparian zone was defined as a horizontal segment of the 300-foot wide analysis area extending from each bank that contained no roads, houses or buildings, yards, grass, or agricultural fields, regardless of vegetation type.

UPPER GREEN RIVER SUB-WATERSHED (RM 64.5 TO RM 93)

Currently, riparian stands along the mainstem Green River within the Upper Green River sub-watershed are composed primarily of small to medium-sized deciduous or mixed deciduous and coniferous stands. Pure stands of coniferous trees account for only 0.2 miles (<1 percent) of the total 39.5 miles of riparian habitat between RM 64.5 and 84.2. Overall, 67 percent (26.5 miles) of the riparian zone is intact and supports vegetation similar to the potential natural community. The remainder is composed of cleared fields or bare ground and emergent wetlands formed due to seasonal inundation of the mainstem Green River and its floodplain by the Howard Hanson Reservoir. Because of the relatively small size of the trees and the amount of riparian zone that is less than 300 feet wide or has been converted to other habitat types, cumulatively riparian zones along the mainstem Green River in the Upper Green River Sub-watershed is considered to be functioning at risk according to the NMFS criteria. Changes in channel morphology and the sediment transport regime that are not explicitly considered by the riparian assessment approach utilized for this report may further impair existing riparian functions in the Upper Green River sub-watershed.

MIDDLE GREEN RIVER SUB-WATERSHED (RM 32 TO RM 64.5)

Riparian conditions in the Middle Green River sub-watershed vary in direct relation to the channel types described in Chapter 2.3, (Hydromodification). The riparian zone within the reach between HHD and Tacoma's Headworks (RM 61 to RM 64.5) is forested but frequently truncated by roads or railroads, as the narrow valley bottom historically provided the easiest access route to the upper sub-watershed. The unconfined Floodplain channel segment between RM 58 and RM 61 is also forested, but the vegetation stands immediately adjacent to the channel are composed primarily of small deciduous trees that became established on formerly active bar surfaces and channel margins following initiation of flood control at HHD in 1964. Most of the riparian zone associated with the Large Contained channel type known as the Green River gorge (RM 45 to RM 57) is intact and composed of large, mixed coniferous and deciduous trees. Agricultural development and flood control structures (levees and revetments) have altered the riparian community somewhat in the wide valley associated with the Floodplain channel type between RM 32 and RM 45. However, riverside parks (including Metzler-O'Grady Park RM 38.5 to RM 40; and Flaming Geyser Park RM 43 to RM 45) and steep bluffs the river impinges on in several locations still support largely intact stands of small to medium sized deciduous trees and mixed coniferous and deciduous forest.

Cumulatively, approximately 84 percent of the riparian zone along the mainstem Green River in the Middle Green River sub-watershed still supports stands of native deciduous or coniferous forest. However, only 53 percent of the Middle Green River has an intact riparian zone at least 300 feet wide. According to the NMFS criteria for riparian function, with the exception of the Green River gorge, riparian zones in the Middle Green River sub-watershed are currently not functioning properly because most are too narrow or support non-native vegetation (bare ground, grass, shrubs or development).

LOWER GREEN RIVER SUB-WATERSHED (RM 11 TO RM 32)

Cumulatively, there is less than one mile of intact riparian zone comprised of medium to large mixed deciduous and coniferous trees along the lower mainstem Green River. Approximately 18 percent (12.4 miles) of the riparian zone in the Lower Green River sub-watershed supports native deciduous trees. However, in most cases, deciduous stands are narrow (<100 feet) or comprised of small, sparse trees mixed with patches of grass, pavement, or bare ground. Almost 50 percent of the riparian zone is comprised of forbs and grass, or shrubs, many of which are non-native. Pavement and bare ground account for approximately33 percent of the total area within 300 feet of the river in this sub-watershed. None of the mainstem riparian habitat in the Lower Green River sub-watershed is in good condition or is considered to be functioning properly based on the NMFS criteria.

GREEN/DUWAMISH ESTUARY SUB-WATERSHED (RM 0 TO RM 11)

Areas of riparian vegetation are limited in extent in the Green/Duwamish Estuary and Elliott Bay and are composed primarily of deciduous trees and non-native shrubs, such as blackberries. Stands of riparian vegetation are found in only three areas in the estuary and bay: between RM 5.3 and 11.0 on the upper estuary, on and near Kellogg Island on the lower estuary, and along Magnolia Bluff on Elliott Bay. These areas represent a relatively small percentage of the total shoreline of the estuary and bay. Between 0 and 7.4 percent of the estuary and bay shorelines support riparian stands that provide some riparian functions (shade, organic matter recruitment, sediment filtration, large woody debris [LWD] recruitment). (Note that categorizations of riparian functions in the estuary and nearshore as good, fair, or poor are based on criteria provided in Table RIP-3 for the upper subbasins; these criteria may not be fully relevant in the estuary and nearshore, as discussed below.) Similar percentages of existing riparian stands are expected to provide fair riparian function. However, up to 35 percent of shorelines in the upper estuary have narrow vegetated zones that provide fair riparian function. The remaining areas of the estuary and bay are dominated by overwater structures, seawalls, and riprap that are sparsely vegetated with grasses or shrubbery and consequently provide poor riparian function.

MAJOR TRIBUTARIES (SOOS AND NEWAUKUM CREEKS)

Little mature native vegetation remains in the riparian zone along mainstem Soos Creek. There is still an intact riparian zone supporting native tree species between RM 1.5 and 2.8, and patches of native deciduous trees also occur elsewhere along the lower six miles of the creek. However, these trees are generally small. The remainder of the riparian zone is composed primarily of shrubs or grass. Development and roads limit the riparian zone width in many cases.

The riparian assessment of Newaukum Creek covered only the areas downstream of RM 10. Much of the middle portion of the watershed has been developed for agriculture. Little mature native vegetation remains along the middle reaches of Newaukum Creek. There is an intact riparian zone supporting native trees from RM 3 to the confluence with the Green River. None of the riparian zone along Newaukum Creek is currently considered to be good or functioning properly according to the NMFS criteria, primarily because the trees that are present are small or medium sized. However, there is approximately 6.8 miles of habitat that is currently in fair condition, and that will develop into good riparian habitat if allowed to mature. Most of this habitat is located in the canyon between RM 0 and RM 3. There also are stands of dense young deciduous trees between RM 6.7 and 7 and along the left bank from RM 7.5 to RM 8.2 that could develop into good riparian habitat in the future.

KEY FINDINGS

UPPER GREEN

- At least 33 percent of the riparian zone has conditions that would be expected to result in poor bank stability because riparian communities there are currently composed of small trees or shrubs. Watershed analysis channel assessments indicate that bank stability may be further compromised by increased sediment delivery and in-channel storage

- Almost 50 percent of the channel length is currently bordered by a riparian zone that is classified as providing poor shade because riparian communities there are currently composed of small trees or shrubs. None of the riparian zone along the mainstem Green River is sufficient to provide good shade conditions.

- The ability to supply organic matter and filter sediments is rated poor along approximately 35 percent of the channel where roads, railroads, or other land uses extend to within 75 feet of the channel.

- Because streamside trees are currently small to medium size, large woody debris (LWD) recruitment is currently rated poor along almost 50 percent of the river. LWD recruitment is not considered to be good anywhere along the mainstem Green River in the Upper Green River sub-watershed.

- Overall, 67 percent (26.5 miles) of the riparian zone in the Upper sub-watershed is intact and supports vegetation similar to the potential natural community.

- Seasonal inundation by Howard Hanson Dam and the permanent presence of roads and railroads within the riparian zone will prevent recovery of riparian functions along approximately 12 miles of the mainstem Green River (approximately 28 percent of the total length).

MIDDLE GREEN

- Cumulatively, approximately 84 percent of the riparian zone along the mainstem Green River in the Middle Green River sub-watershed still supports stands of native deciduous or coniferous forest. However, only 53 percent of the Middle Green River has an intact riparian zone.

- Riparian conditions within the Middle Green River sub-watershed vary according to channel type and adjacent land use.

- Agriculture or rural residential land uses have cleared riparian communities to within 75 feet of the bank in almost 25 percent of the riparian zone, resulting in conditions that would be expected to result in poor bank stability.

- Due to the small size of existing riparian trees or the truncated width of the riparian zone, almost 30 percent of the channel length in the Middle Green River is currently classified as providing poor shade. Of the 45 miles of riparian zone currently classified as providing fair to good shade, 65 percent is located within the undeveloped Green River gorge. Due to the large size of the mainstem Green River in the Middle Green sub-watershed, shade conditions may never achieve levels classified as good according the criteria utilized for this evaluation.

- The ability to supply organic matter and filter sediments is rated poor along approximately 27 percent of the channel because of small trees or a narrow riparian zone.

- Large woody debris recruitment is currently rated poor along almost 38 percent of the river where the riparian zone is less than 150 feet wide or is dominated by small trees. The 22.6 miles of riparian zone considered to have good LWD recruitment is located almost entirely within the Green River gorge.

- A number of riverside parks (including Metzler-O'Grady Park RM 38.5 to RM 40; and Flaming Geyser Park RM 43 to RM 45) still support largely intact stands of small to medium sized deciduous trees and mixed coniferous and deciduous forest that could develop good riparian function if undisturbed by future landuse activities.

LOWER GREEN

- Levees and revetments have fixed the channel into place and effectively prevent bank erosion even where gradual channel migration would occur naturally, effectively halting an important mechanism of large woody debris recruitment to the lower mainstem Green River.

- There is less than one mile of intact riparian zone comprised of medium to large mixed deciduous and coniferous trees along the lower mainstem Green. Approximately 18 percent (12.4 miles) of the riparian zone in the lower Green River sub-watershed supports native deciduous trees; however in most cases deciduous stands are narrow (<100 feet) or comprised of small, sparse trees mixed with patches of grass, pavement or bare ground.

- Almost 50 percent of the riparian zone is comprised of forbs and grass, or shrubs, many of which are non-native.

- Over 80 percent of the riparian zone is currently considered to provide poor shade, organic matter recruitment, and sediment filtration because native vegetation communities have largely been converted to grass or shrubs and because development often extends to within 75 feet of the channel.

- Ninety seven percent of the riparian zone is considered to have poor LWD recruitment potential and microclimate conditions because native vegetation communities have largely been converted to grass or shrubs, and because development often extends to within 75 feet of the channel. None of the riparian zone along the lower Green River is considered to have good LWD recruitment potential.

- Pavement and bare ground account for approximately 33 percent of the total area within 300 feet of the river in the lower Green River sub-watershed.

GREEN/DUWAMISH ESTUARY

- The majority of the upper intertidal zones in both the estuary and in Elliott Bay are supplanted with riprap, seawalls, and overwater structures.

- The upper estuary between RM 5.3 to RM 11.0 supports the largest proportion of riparian vegetation, although these stands are not wide enough to provide high quality riparian functions.

- Riparian vegetation is sparse in the lower estuary (RM 5.3 to the mouth).

- Functional riparian stands on Elliott Bay are limited to Magnolia Bluff and represent less than 14 percent of the bay shoreline.

- The remaining riparian areas of the lower estuary and bay are dominated by overwater and inwater structures.

MAJOR TRIBUTARIES: SOOS CREEK (RM 0.0 –13.0) AND NEWAUKUM CREEK (RM 0.0-10.0)

- Sections of intact riparian zone that currently support small to medium sized deciduous and mixed conifer and deciduous trees are concentrated in the canyon sections of both Soos and Newaukum Creeks from around RM 0 to RM 3.

- Bank stability, shade, and organic matter recruitment is considered poor along approximately 65 percent to 80 percent of Soos Creek and 53 percent of Newaukum Creek because of development that extends to within 75 feet of the channel or because trees are currently small.

- None of the riparian zone along Soos Creek is currently considered to provide good LWD recruitment because of development that extends to within 75 feet of the channel or because trees are currently small.

- Sixty percent of the riparian zone along Newaukum Creek currently provides poor LWD recruitment. The remaining 40 percent of the riparian zone analyzed currently has fair LWD recruitment and may develop good conditions if left undisturbed.

- Impairment of riparian functions along mainstem Soos Creek occur primarily as a result of industrial (including powerline corridors) or residential development adjacent to the stream.

- Impairment of riparian functions along mainstem Newaukum Creek occur primarily as a result of agricultural or residential development adjacent to the stream.

DATA GAPS

- A field reconnaissance of riparian conditions using a consistent methodology designed for application at the appropriate stream/river scales has not been conducted for most of the watershed.

- Information on riparian conditions between RM 77 and RM 88 in the Upper Green River sub-watershed is based primarily on watershed analyses that considered only riparian conditions within 100 feet on each side of the river.

- Information on riparian conditions between RM 64.5 and RM 77 were derived from USFS GIS layers constructed from LandSat imagery, which is known to have a high rate of inaccuracy.

- None of the remote sensing data utilized for this assessment was validated in the field by the author.

- The current analysis of bank stability is not based on a field data and therefore may be highly inaccurate where site-specific conditions influence this riparian function.

- The analysis of shade conducted for this report does not consider topographic shading.

- Assumptions of riparian functional conditions based on tree size were developed for use in smaller rivers and may not accurately reflect conditions relative to the mainstem Green River.

- Knowledge of the functions of riparian vegetation in the estuary and nearshore areas is limited and largely extrapolated from information on riparian functions along streams in upper watersheds, lowland streams, and studies of marine riparian vegetation functions in marine and estuarine environments elsewhere.

INTRODUCTION

Riparian ecosystems are complex assemblages of organisms and their environment existing adjacent to and near water (Lowrance et al.1985). Along riverine systems, riparian zones connect mountainous headwater streams with lowland floodplains and estuaries, providing avenues for the transfer of water, sediment, wood and organic matter, nutrients, and aquatic organisms. Riparian zones are corridors of disturbance, occupying a complex mosaic of landforms that support biological communities that are often more heterogeneous and diverse than upslope landscapes (Agee 1988; Gregory et al. 1991). In pristine mountainous environments, natural disturbance of riparian zones along small, steep headwater channels is most often the result of landslides and debris flows that occur on an infrequent basis. Streams that have not experienced a recent mass-wasting event frequently support forest vegetation communities similar to those of the surrounding uplands, while recently impacted channels are initially recolonized with fast growing early successional species such as red alder (Gecy and Wilson 1990). Moving downstream, the size of the river increases and low gradient alluvial landforms become more prevalent. Along mainstem rivers, riparian disturbance is most often caused by flooding, which erodes banks and creates new landforms through the variable scour and deposition of sediment (Agee 1988). The alluvial landforms formed by the river as a result of a series of disturbances support a variety of even-aged stands composed of species such as red alder, willow, or cottonwood that rapidly colonize disturbed sites. Young forests established following disturbances often exist within a matrix of older forests composed of later successional species such as western redcedar, Sitka spruce, and western hemlock that persist on landforms not affected by recent floods (Abbe and Montgomery 1996; Bayley 1995).

Riparian zones perform many functions that are essential to the survival and productivity of salmonids and other aquatic organisms. The effects of riparian vegetation on streams decrease with increasing distance from the stream, and the rate of this decrease varies between the different functions (Figure RIP-1). A number of excellent reviews have been published recently on the subject of riparian function, the influence of land use and management activities on riparian function, and the buffer widths necessary to maintain properly functioning riparian habitats including Wenger 1999; Knutsen and Naef 1997; FEMAT 1993; Castelle et al. 1994; Johnson and Rhyba 1992. The reader is referred to those documents for an in-depth discussion of those topics.

Although extensive research has been done on freshwater riparian functions, very little research has been conducted to identify riparian functions in estuarine or marine systems. Brennan and Culverwell (in prep.) hypothesize that marine riparian zones provide functions similar to those provided by freshwater riparian zones and that marine riparian zones are likely to provide additional functions unique to nearshore systems.

The following text briefly reviews important riparian functions relevant to the Green River and their effects on salmonids, including:

- Bank stabilization;
- Supply of organic matter and nutrients;
- Shade;
- Large woody debris recruitment;
- Filtration of sediment;
- Channel migration zones; and
- Microclimate.

Based on the literature reviews cited above, the width of riparian zone sufficient to maintain each individual function on each bank is identified (Table RIP-1). The widths cited are not intended to be used as a recommendation for required riparian buffer widths but simply to facilitate an evaluation of the current status of individual functions at various locations along the Green River. As noted above, disturbances influence riparian zones even in unmanaged watersheds. Consequently, conditions naturally vary throughout the stream network over both space and time and realistically could never be expected to be in good condition throughout an entire watershed at any given time. The distribution of riparian habitat conditions necessary to provide for fish needs cannot be specified, but restoring or maintaining the distribution, diversity, and complexity of the various disturbance patterns should result in properly functioning riparian ecosystems.

BANK STABILITY

One of the most important functions of riparian vegetation is bank stabilization (bank stabilization for the purposes of this discussion refers only to the active contribution of roots at resisting lateral bank erosion and does not address resistance to channel avulsion, long-term channel migration, or concerns about slope stability). The roots of streamside vegetation bind unconsolidated soil particles together, increasing the bank's resistance to erosive forces. Stream-adjacent riparian vegetation and root systems also increase surface roughness, decreasing flow velocity and dissipating the erosive energy of high flows. In a study of 748 stream bends on rivers located in southern British Columbia, 67 percent of the unvegetated bends experienced erosion during a storm, while only 14 percent of the vegetated bends eroded (Beeson and Doyle 1995). Non-vegetated bends were more than 30 times as likely to suffer exceptionally severe erosion as fully vegetated bends (Beeson and Doyle 1995). Erosion of channel bends is a natural process and occurs whether mature riparian vegetation is present or not. However, mature trees with intact root masses slow the rate of erosion. They protect the bank from further erosion or serve as a source of large woody debris when they are undercut and topple into the river.

The extent of the root system of an individual tree is roughly equivalent to its crown diameter. Consequently, trees located more than ½ crown diameter from the channel exert little influence on bank stability (Burroughs and Thomas 1977). The average maximum crown diameter for deciduous species commonly found along the Green River, including red alder, bigleaf maple and cottonwood, is 88 feet; maximum crown diameters for coniferous species are somewhat smaller, averaging 68 feet for western redcedar, western hemlock, Douglas-fir, and Sitka spruce (Thomas 1999). Thus, riparian zones with a horizontal width of at least 44 feet wide should be sufficient to provide effective bank stability (Table RIP-1). Small trees and shrubs presumably have shallower, smaller root systems. Small trees or shrubs may provide adequate bank stability in small streams. In the case of the mainstem Green River, it is assumed that medium to large trees are required for optimum bank stabilization.

Channel bank vegetation, including roots, sod, and leaf mats is less effective in controlling the rate of bank erosion and channel migration in estuaries than in smaller streams because of the generally greater flow volumes and because of the nature of the underlying soils. In the estuary, stream bank soils consist of sands and silts that have been deposited by river action over the recent geologic history. Such soils are often highly erosive and the root structure of riparian vegetation is easily undermined, especially given the fluctuations in tidal and flow elevations that occur.

In certain situations, however, vegetation can form an effective deterrent to erosion. For example, much of the shoreline of tidal portions of lower river systems is vegetated with marsh plants (rushes, cattails, grasses, shrubs) below ordinary high water (OHW). These plants tend to trap river-born sediments and form near-horizontal benches; the benches, in turn are stabilized by the root mats of the marsh plants. In such areas, the vegetated riparian zone function of bank stabilization is provided by plants that extend well below the OHW line.

The great majority of shoreline in the Duwamish estuary is contained by levees, dikes, or revetments, constructed early in the last century to allow flood plain development and agriculture (see Chapter 2.3, Hydromodification). In these areas, the role of vegetation in bank stabilization has been largely pre-empted by artificial structures. Nonetheless, riparian vegetation, especially emergent marsh and scrub shrub, is important in maintaining the stability of some of these earthen structures.

SHADE

Canopy cover that provides shade is an important factor governing stream heating and cooling. On small streams, shade is one of the most important determinants of water temperature. Both daily and annual fluctuations in water temperature are moderated by the shade of streamside vegetation (Beschta et al. 1987). In forested watersheds, mid-day summer water temperatures rise only 1-2 ^{o}C above year-round average water temperatures (Beschta et al. 1987). In contrast, water in streams where the riparian canopy has been removed may experience temperature increases of 7 to 16 ^{o}C (Beschta et al. 1987). In the winter, riparian vegetation prevents the rapid and excessive cooling of the stream (Knutsen and Naef 1997). In general, stream surfaces should have 60 to 80 percent shade throughout the day to maintain water temperature (Budd et al. 1987). In western Washington, stream temperatures are also strongly influenced by elevation; at elevations above 3,600 feet, environmental conditions are such that streams are not likely to exceed 16^{o}C even if there is no canopy cover (Sullivan et al. 1990).

Studies reviewed by Knutsen and Naef (1997) suggest that buffers 90 feet wide or greater are required to maintain recommended shade levels (Table RIP-1). However, most of the studies reviewed by Knutsen and Naef (1997) relate specifically to small (1st through 3rd order) streams. Wide streams are less likely to be completely shaded by stream-adjacent vegetation even with intact native riparian communities (WFPB 1997). Given a solar angle of 60 degrees (typical for western Washington in June through August), the height of vegetation required to provide shade to the middle of the stream nearly equals the stream width (Figure RIP-2). Thus, a stand of 150 foot tall mature Douglas-fir would shade a 173 foot wide stream. In addition, both the direction of flow and topography can also influence shade. Steep sideslopes or canyon walls can provide significant amounts of topographic shade.

As noted above, potential direct influence of shading on air and water temperatures over and in larger order streams is limited. Even with a densely forested riparian zone of one potential tree height in width, shading will only cover the margins of the stream during mid-day hours when insolation is greatest. Greater water depths only allow a small fraction of the water column to be influenced by solar heating or shading. Tidal circulation and mixing of marine waters with stream flow in the lower estuary and nearshore areas further limits the influence of shading on water temperatures. The influence of riparian zone shading is also limited during low water periods when water volumes are at a minimum; under these conditions shading may only fall on exposed mudflats, not on the water surface.

Shading remains an important factor in moderating temperatures in certain cut-off sloughs and small tributaries to the larger tidal waters; juvenile salmonids may venture into these areas during their estuarine residence. Smaller distributary channels, such as the area behind Kellogg Island, may carry such a low flow volume that some influence of shading might be measured in water temperature.

In nearshore areas of Puget Sound, shading of the upper intertidal beach plays a critical role in limiting the upward distribution of intertidal plants and animals (e.g., Foster et al. 1986). Typically the upper elevation at which intertidal biota can live is dictated by the degree of desiccation experienced during low tides. Rate of desiccation is clearly reduced on shorelines with a forested riparian zone; the influence of shading is dependent on the orientation of the shoreline with maximum shade on beaches with northern exposure. Shading is especially important in the nearshore in areas of surf smelt or sand lance spawning. These species spawn in the upper intertidal zone of sandy or sand and gravel beaches. In some areas of Puget Sound, surf smelt spawning occurs year round and Pentilla (D. Pentilla, WDFW, personal communications, 2000) reports that this spawning behavior occurs primarily on well-shaded beaches. In otherwise suitable spawning areas that lack shade, spawning only occurs during the fall through spring months and egg survival may be reduced. Pentilla has also shown that surf smelt egg survival from summer spawning is higher on shaded versus unshaded beaches.

ORGANIC MATTER AND TERRESTRIAL INVERTEBRATE RECRUITMENT

Riparian zones are the dominant contributors to the aquatic food chain, particularly in smaller streams (Vannote et al. 1980). Leaves, wood, insects, and other materials fall into the stream from overhanging vegetation. Some species (e.g., aquatic invertebrates, whitefish) feed directly on vegetative detritus; these species in turn serve as a food source for anadromous and resident salmonids. The distance away from the stream from which organic matter and terrestrial inputs originates depends on site-specific conditions, but it generally declines at a distance equal to about one-half tree height (FEMAT 1993). This distance will range from 50 to 75 feet depending on the potential height of native vegetation and the slope of land adjacent to the channel (Table RIP-1). Because they are shorter, small trees or shrubs are assumed to provide less organic matter and terrestrial insect inputs than medium to large size trees.

In larger streams, the cumulative material transported downstream from upstream reaches becomes a more important source of organic matter than that produced locally. In addition, in reaches with extensive floodplains, large amounts of organic matter are recruited to the channel by overland flows during floods. Finally, salmonids themselves were historically an important source of nutrients to both riverine and riparian ecosystems. Carcasses deposited on the floodplain during overbank flows or caught on large woody debris in the channel provide nutrients that benefit many different species, ranging from salmonids and other aquatic fishes, to bears, to riparian vegetation itself (WDFW 2000).

Riparian vegetation along estuarine channels and in marshes plays well-recognized roles in production of organic litter for local detritus based food webs and for export to other ecosystems (e.g., Simenstad and Thom 1996) and production of insect prey for local consumption by juvenile salmonids (e.g., Simenstad and Cordell 2000). Marsh vegetation (below Ordinary High Water) in broad brackish and salt marshes and in linear marsh fringes along tidal channels can provide much of the organic litter and invertebrate prey production functions that riparian vegetation above OHW does along freshwater streams and rivers. Where it occurs, marsh vegetation is likely to be more important in the production of prey for juvenile salmonids than scrub-shrub or forest vegetation that may border the marsh above OHW; the marsh vegetation is simply closer to (or in) the water more of the time so that associated insects are more likely to be transported into the water.

SEDIMENT FILTRATION

As noted in earlier chapters, when erosion and sedimentation delivery exceed natural rates, fish and other aquatic biota may be negatively impacted. One of the most important functions of riparian vegetation is to inhibit sediment from entering streams. Intact riparian buffers also keep soil disturbing activities away from streams, preventing erosion and delivery of sediment from exposed soils. Although overland flow is rare in fully forested areas, in developed watersheds, densely-vegetated riparian zones reduce the velocity of overland flow from nearby exposed soils or impervious surfaces, enhancing infiltration of the water and deposition of the sediment. The numerous obstructions and storage sites formed by the roots, stems, and abundant litter associated with intact riparian zones trap and retain sediment before it is delivered to the stream channel. Riparian vegetation also is important for trapping sediment transported downstream by overbank flows during large floods. That latter function was not assessed for this report.

Numerous studies have documented the effectiveness of vegetated buffers at trapping sediment transported by surface runoff. According to Knutsen and Naef (1997), the results of eight separate studies conducted in forested areas suggest that buffer widths effective at controlling fine sediment range from 26 to 300 feet (Table RIP-1). Wenger (1999) reports that studies from agricultural and urban landscapes indicate grass buffers as narrow as 15 feet wide can reduce total suspended sediment loads by over 80 percent. Based on the studies Wenger (1999) reviewed, buffer widths of 82 feet are the most efficient at removing sediment; beyond that large increases in width resulted in small reductions in sediment. Wenger (1999) further notes, however, that researchers in forested landscapes typically found that buffers at least 98 feet wide were needed to prevent impacts to aquatic habitats. In addition, a number of researchers have noted that for controlling delivery of fine sediment, riparian buffers are especially important along smaller headwater streams that make up the majority of the stream network miles in any watershed (Osborne and Kovavic 1993; Lowrance et al. 1997).

Riparian vegetation along tidal waters is likely to be as effective at trapping finer sediments being carried to the shoreline from upland sources as is riparian vegetation along streams. In estuarine areas with limited circulation (e.g., cut-off sloughs) silt carried to the surface water can increase water turbidity significantly and in such areas the role of riparian vegetation in controlling overland sediment movement is similar to that in freshwater areas.

Storm drains and ephemeral streams can also deliver larger volumes of water from an entire shoreline drainage basin through a point source of flow onto the beach. In these cases, riparian conditions along the course of the stormwater flow from the uplands are important in dictating water quality upon entering the tidal water body. Marsh vegetation (below Ordinary High Water) in broad brackish and salt marshes and in linear marsh fringes along tidal channels provides the same sediment retention function that riparian vegetation above OHW does along freshwater streams and rivers.

LARGE WOODY DEBRIS RECRUITMENT

Large woody debris (LWD) serves many important functions in stream channels. Wood creates pools, captures, sorts and stores sediment, stabilizes the stream bed and banks, provides cover from predators and high flows, and retains nutrients and organic matter. Large logs of decay-resistant coniferous species such as western redcedar, Douglas-fir, and western hemlock are the most valuable because they form features that may persist in the streambed for over 100 years (Franklin et al. 1981). Large deciduous trees such as bigleaf maple or black cottonwood can also serve as key pieces of large woody debris, although they generally decay more rapidly than coniferous logs (Harmon et al. 1986). Large logs with attached rootwads are particularly important as “key pieces” in large rivers (Abbe and Montgomery 1996). For a river 50 to 65 feet wide, a key piece would consist of a log with a total volume of 318 cubic feet (at least 2 feet in diameter and up to 100-feet long) (Schuett-Hames et al. 1999).

Seven studies reviewed by Knutsen and Naef (1997) indicated that most wood is recruited to streams from within 150 feet of the channel (Table RIP-1). In general, smaller wood is stable and functional in smaller streams, while large streams require large logs or accumulations of woody debris (jams) to maintain desired aquatic habitat attributes (Perkins 1999). Riparian vegetation along undisturbed small, mountainous headwater streams is generally composed of species similar to the surrounding uplands (Doughty 1996). Although deciduous trees may colonize channels disturbed by debris flows and rapidly reach the minimum “functional” size, medium to large size coniferous trees are generally required to supply long-lasting LWD and to serve as barriers to the propagation of future debris flows or dam break floods (Coho 1993). Thus, optimum riparian habitat conditions in small mountainous streams are composed of medium to large confers or mixed coniferous and deciduous stands.

In marshes, LWD may play a role in the formation of channels or deeper pockets that retain water during low tide. LWD stranded in marsh areas also provides a substrate for the establishment of vegetation, including marsh plants or even trees (Brennan and Culverwell, in prep.; J. Houghton, Pentec Environmental, pers. obs.). In areas of broad marsh habitat, directly recruited LWD will fall onto upper marsh terraces where it is seldom and incompletely inundated. Unless the marsh is crossed by channels, fish may never have access to the area of the LWD. Relatively smaller sizes of LWD can be retained in lower energy, off-channel estuarine habitats and thus provide the same functions as larger LWD in more active channels. Consequently, relatively young stands of alder and cottonwood can provide functioning LWD in estuaries and nearshore areas. Even if the trees decay in 20 or 30 years, they may be continually replaced with other 20- to 30-year old trees. Mature trees considered for this purpose are those with diameter at breast height (dbh) of > 0.3 m. Trees that recruit directly to the estuary or nearshore from the adjacent riparian zone are assumed to have limbs and rootwads attached, thus adding to their function as refuge, despite a smaller size. Large wood also provides for organic contributions to the estuary and nearshore and thereby supplements the detrital base (Maser and Sedell 1994).

LWD anchored or buried in the beach plays a role in stabilizing beach sediments by limiting shoreline erosion and long-shore sediment transport (Brennan and Culverwell, in prep.). Little LWD is retained along areas with a hardened shoreline (bulkhead or riprap) although occasional logs may lodge in riprap or be deposited at the top of riprapped slopes by high tides.

CHANNEL MIGRATION ZONE

In unconfined streams where the channel migrates back and forth across the floodplain over time, wood may be recruited to the channel from throughout the channel migration zone (CMZ). The channel migration zone is defined as the lateral extent of likely movement along a stream reach with evidence of active channel migration or avulsions over the past 100 years (WFPB 2000). Vegetation in the channel migration zone of large rivers is typically patchy, ranging from young early successional vegetation that colonizes recently active bar surfaces to large old growth coniferous or deciduous trees on stable floodplain terraces (Abbe and Montgomery 1996; Bayley 1995). Although riparian habitat conditions characteristic of large meandering rivers typically consist of multiple stands of varying age and species, large coniferous or deciduous trees are required to provide functional and key sized LWD. Consequently, upstream reaches or stands of older trees located within or immediately adjacent to the CMZ are particularly important sources of wood.

Conditions within the channel migration zone also have the potential to influence the future effectiveness of the various riparian functions described above. For example, a 200 foot wide band of large mixed conifer and deciduous trees may maintain sufficient shading, bank stability, and sediment filtration under current conditions. However, if the channel migrates laterally over time and the remainder of the channel migration zone has been cleared and converted to farm fields, future riparian conditions are likely to deteriorate as the channel moves across the CMZ. Intact native vegetation communities within the channel migration zone are also important for maintaining natural rates of lateral channel migration and the frequency of channel avulsions.

In the Duwamish estuary, the CMZ is limited to the top of the existing hardened shorelines.

MICROCLIMATE

The presence of surface and sub-surface water and abundant vegetation in riparian zones results in a microclimate that is moister and more moderate (cooler in summer and warmer in winter) than the surrounding areas (Knutsen and Naef 1997). These conditions provide an environment that is desirable to many species, particularly amphibians (Knutsen and Naef 1997). Microclimate is believed to be influenced by the width of both the stream channel and the riparian zone. Although there are no reported specific field investigations of the extent of riparian microclimate (FEMAT 1993), general ecological theory and observations suggest that riparian microclimate effects may extend two to three tree heights (up to 525 feet) into the surrounding forest (Table RIP-1) (Harris 1984; Franklin and Forman 1987). For the purpose of this report, it is assumed that dense stands of large trees (deciduous, coniferous, or mixed) would provide optimal microclimate conditions.

The presence of intact riparian stands along estuarine and nearshore areas provide an important microclimate for wildlife and may influence prey production and salmonid feeding and refuge habitat.

OTHER FUNCTIONS

In addition to the functions evaluated for fish and aquatic habitat, riparian zones also play an important role as wildlife habitat. Riparian zones have a higher species diversity than any other habitat type (Oakley et al. 1985). Terrestrial wildlife and many bird species rely on riparian zones because the habitat provided is structurally diverse, contains abundant sources of water and food, and serves as travel corridors to and from other ecosystems (Knutsen and Naef 1997). Amphibians are particularly abundant in riparian zones because of the abundant water and moist and moderate microclimate (Bury et al. 1991).

ANALYSIS METHODS

Historic riparian conditions were inferred based on early descriptions of the vegetation of the Green River watershed or similar nearby areas (Pence 1946; Smalley 1883). For the lower Green River and Green/Duwamish estuary, a vegetation map produced by the USGS in 1894 provides some information on pre-settlement riparian and floodplain vegetation patterns. Even at that early date, much of the lower Green River valley had already been subjected to forest harvest or agricultural development.

Current riparian condition was assessed based on vegetation type, size, and density, generally corresponding with the methodologies recommended by the Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) and the Washington Forest Practices Board Manual (WFPB 1997) (Table RIP-2). Existing data were utilized where possible. In the Upper Green River sub-watershed, Plum Creek Timber Company has completed draft or final riparian assessment reports for the Lester, Upper Green, and Sunday Creek Watershed Administrative Units (WAUs) using the Washington Department of Natural Resources Methodology. In addition, the U.S. Forest Service compiled GIS data on vegetation types and stand ages within 300-foot wide “riparian reserves” on each side of the mainstem Green River for a federal watershed analysis of the entire Upper Green River sub-watershed (USFS 1996). The USFS watershed analysis did not specifically evaluate riparian conditions. However, the GIS data were used to assess current riparian conditions for this report. For portions of the Middle and Lower Green River sub-watersheds, King County compiled a map of riparian cover types within a 300-foot wide band on each side of the low flow channel of the mainstem Green River between RM 0 and RM 45.7 based on analyses of aerial photos dating from 1994. No independent field validation was conducted of any of the data obtained from these sources.

In areas where no existing riparian data were located (RM 45 to RM 64.5 of the mainstem Green River; Soos and Newaukum Creeks), an original assessment was conducted specifically for this report using 1:12,000 black and white orthophoto quads flown in 1999 and 1:12,000 scale color aerial photos flown in 1996. To maintain consistency with the USFS and King County data sets, original analyses conducted for this report covered the area within 300 feet on each side of the stream channel. The predominant cover type within this zone was identified, and stands of trees were further classified by size and density (Table RIP-2). The width of the vegetation community immediately adjacent to the channel was recorded (to the nearest 25 feet) and other vegetation or cover types occurring within the 300-foot wide analysis area were noted (if present). The presence of roads, buildings, or developments within the riparian zone was recorded. No field validation was conducted in any of the areas for which an original analysis was conducted for this report.

The current status of each of the riparian functions described above was assessed based on the riparian cover type and density. Criteria used to evaluate each individual riparian function for this report were developed based on the width of existing streamside shrub or tree community and on the vegetation size and age, in general accordance with the approach employed by Washington Watershed Analysis riparian function assessment module (WFPB 1997). Specific criteria used to determine the current status of each individual function considered by this report are summarized in Table RIP-3. Although tidal estuarine habitats predominate in the Duwamish River and Elliott Bay, the same criteria were used to assess those areas. As reported, very little research has been conducted to identify riparian functions specific to estuarine systems.

At a minimum, a riparian zone in good condition had to meet the width requirements for that condition category. Once the current width of the riparian zone was established, the existing condition evaluation was modified based on vegetation type. For example, a riparian zone that was 75 feet wide but that consisted predominantly of shrubs would be classified poor in terms of bank stability. Similarly, a riparian zone that was 75 feet wide and supported large dense coniferous would be in good condition in terms of bank stability but in poor condition in terms of LWD recruitment, because it did not meet the minimum width requirement (≥150 feet) for sufficient LWD recruitment. Riparian condition was assessed separately for each bank of the river.

Finally, the length of river with an "intact" riparian zone and the length of channel bordered by vegetation similar to the potential natural community was estimated. For the purposes of this report, an "intact" riparian zone was defined as a segment of the 300-foot wide analysis area extending from each bank that contained no roads, houses, or buildings, yards, grass or agricultural fields, regardless of vegetation type. The presence of levees did not exclude a channel segment from being classified as having an intact riparian zone unless there was clear evidence of a regularly used road on top of the levee. However, as noted in Chapter 2.3 (Hydromodification), levees and revetments have a profound influence on channel morphology and natural geomorphic processes, and thus impede some important riparian functions such as LWD recruitment. For the mainstem Green River, deciduous, coniferous, or mixed stands of trees of any size were considered to be representative of the potential natural community.

As defined by NMFS (1999), if the riparian community in any sub-watershed is more than 80 percent intact and at least 50 percent of the vegetation community is similar to the potential natural community, the riparian management zone is considered to be "properly functioning" (which was considered equivalent to "good" in the rating system employed for this assessment). If the riparian community is less than 70 percent intact and less than 25 percent of the vegetation community is similar to the potential natural community, the riparian management zone is considered to be "not properly functioning" (which was considered to be equivalent to "poor" in the rating system employed for this assessment). Conditions between these criteria are considered to be "at risk" (which is considered to be equivalent to "fair" in the rating system employed for this assessment). Intact riparian and channel migration zones with vegetation similar to the potential native vegetation represent locations where good habitat conditions could be restored, even if the current vegetation type or age does not provide for optimal riparian habitat function.

The following sections qualitatively describe the historic riparian zone characteristics associated with the mainstem Green River, and they provide a reconnaissance level evaluation of current riparian conditions and function based on the widths identified in Table RIP-1.

UPPER GREEN RIVER (RM 64.5 TO RM 93)

Riparian conditions in the Upper Green River Sub-watershed were evaluated based on data generated for watershed analyses conducted by the USFS (USFS 1996) and Plum Creek Timber Company (Plum Creek 1996; 1997). One limitation of the Plum Creek watershed analyses is that riparian conditions were evaluated only within 100 feet on either side of the channel, as recommended by the Washington Forest Practices Board Methodology (WFPB 1997). The USFS riparian reserve stand data were used to estimate whether the conditions described by Plum Creek extended out to 300 feet. Although the USFS data are considered less accurate due to the original source of the data, they were assumed to be representative of the outer portion of the riparian zone unless maps indicated that roads, railroads, or cleared areas were present within 300 feet of the stream.

HISTORICAL CONDITION

Little specific information is available on the historic condition and composition of riparian zones along the mainstem Green River in the Upper Green River sub-watershed. The Upper sub-watershed is located predominately in the western hemlock potential vegetation zone (USFS 1996). In this zone, western hemlock and western redcedar represent climax species, while Douglas-fir is the sub-climax species (Franklin and Dryness 1973). Tree species commonly found in early seral riparian zones consist of red alder, black cottonwood, bigleaf maple and Oregon ash. Western redcedar and western hemlock will eventually develop in the absence of disturbance. Large cedar stumps observed on the floodplain and terraces along the Green River and lower Sunday Creek provide evidence that the riparian zone historically supported large coniferous trees (Ehlert 1997).

CURRENT CONDITIONS

Currently, riparian stands along the mainstem Green River within the Upper Green River sub-watershed are composed primarily of small to medium-sized deciduous or mixed deciduous and coniferous stands (Figure RIP-3). Pure stands of coniferous trees account for only 0.2 miles (<1 percent) of the total 39.5 miles of riparian habitat between RM 64.5 and 84.2. Overall, 67 percent (26.5 miles) of the riparian zone is intact and support vegetation similar to the potential natural community. The remainder is composed of cleared fields or bare ground and emergent wetlands formed due to seasonal inundation of the mainstem Green River and its floodplain by the Howard Hanson Dam reservoir. Because of the relatively young age of the trees and the amount of riparian zone that is less than 300 feet wide or has been converted to other habitat types, cumulatively riparian zones along the mainstem Green River in the Upper Green River Sub-watershed is considered to be functioning at risk according to the NMFS criteria. Changes in channel morphology and the sediment transport regime that are not explicitly considered by the riparian assessment approach utilized for this report may further impair existing riparian function.

BANK STABILITY

Based on the criteria in Table RIP-3, bank stability is rated good along 21.6 miles (50 percent) of the river bank downstream of RM 84.2 (Table RIP-4). Bank stability is rated fair along 17 percent of the banks, primarily because of the small size of existing riparian trees. Bank condition is rated poor along the remaining 14 miles of river bank (33 percent of all mainstem riparian zones). Riparian zones in poor condition include the seasonally inundated zone of Howard Hanson Reservoir (RM 65.5 to RM 69) and locations where roads or railroads are located within 25 feet of the channel, which, as noted in Chapter 2.3, affect approximately five total miles of riparian zone.

The bank stability ratings developed for this are based solely on current vegetation conditions as identified by remote sensing data or aerial photo analysis and may not accurately reflect existing bank stability on the mainstem Green River in the Upper Green River sub-watershed. For example, in the Lester WAU, increased sediment delivery has destabilized the mainstem channel in many locations, resulting in fluctuating channel widths and conversion of Floodplain channel types to braided reaches. In 1995, bank erosion near the Lester airstrip at RM 83 resulted in a major channel avulsion where the channel moved out of a reach with a densely forested riparian zone and into an area where all the trees had been cleared and converted to a grassy field (Goetz 2000; Cupp and Metzler 1996). No field data were located describing bank conditions in the remainder of the mainstem, but similar instances of unstable banks are expected to occur there.

SHADE

The area of a stream channel shaded by the riparian zone is directly related to the height and density of vegetation, particularly in unconfined Floodplain channel types such as the mainstem Green River between RM 64.5 and RM 88. Because the riparian zone along the mainstem is currently dominated by small trees, shade is rated as poor in approximately 50 percent of the riparian zone assessed along the mainstem Green River in the Upper Green River sub-watershed (Table RIP-4). The remaining 50 percent of the riparian zone has fair shade, primarily because the trees there are currently only medium sized and are not yet tall enough to shade the entire wide mainstem channel. None of the riparian zone is considered to provide good shade. Shade was mapped as “naturally low” along the mainstem Green River in the Lester Watershed Analysis (Doughty 1996). However, mature riparian stands composed of 150 to 200 foot tall coniferous trees such as western redcedar or western hemlock would be expected to provide substantial shade to the 100 to 200 foot wide mainstem. While it is difficult to estimate the length of channel that such conditions might prevail upon under natural conditions, it is anticipated that shade would be substantially greater than it is currently.

ORGANIC MATTER AND TERRESTRIAL INVERTEBRATE RECRUITMENT

Like shade, organic matter (OM) and terrestrial insect inputs are directly related to the height and density of riparian vegetation. While shrubs and small trees may provide substantial amounts of litter to small channels, recruitment of OM on larger rivers is reduced when riparian zones are dominated by small trees or shrubs. Under current conditions, only about 22 percent of the 42.8 total miles of riparian zone provides good OM and terrestrial insect inputs (Table RIP-4). The majority of the remaining riparian zone provides only fair to poor recruitment of organic matter and terrestrial insects.

SEDIMENT FILTRATION

Even low growing vegetation such as shrubs or small trees can be very effective at filtering fine sediments as long as the stand is dense (Wenger 1999). The ability of the existing riparian zone to filter sediment is considered to be good in approximately 56 percent of the riparian zone evaluated along the mainstem Green River. Sediment filtration is poor along the 7.0 miles of bank within the seasonally-inundated reach (RM 65.5 to 69) and at locations where roads, powerline corridors, or railroads are located within 200 feet of the stream.

LARGE WOODY DEBRIS RECRUITMENT

To achieve a good rating for large woody debris (LWD) recruitment, riparian stands must contain trees of the appropriate species that are large enough to provide functional or key-sized pieces of LWD. The mainstem Green River is a large channel that ranges from 100 to 200 feet wide. Consequently, only very large pieces of wood are expected to be functional. Although coniferous species are preferred, a variety of stand types would occur naturally adjacent to large Floodplain channels such as the mainstem Green River and large trees of any species were considered to provide good LWD recruitment. At present, only one of the riparian stands evaluated contained large trees, and this stand is truncated by a road within 100 feet of the channel. Approximately 50 percent of the riparian habitat is rated fair, because the stands currently consist of medium-sized trees. Those areas should develop good LWD conditions within several decades provided they are undisturbed by harvest or floods. The remaining 50 percent of the riparian zone was considered to be in poor condition. Of this, at least 12 of the 21.2 miles (approximately 28 percent of the entire mainstem riparian zone) is classified as poor because of the presence of roads or railroads, or because it is seasonally inundated by Howard Hanson Reservoir. Seasonal inundation prevents establishment and growth of native trees. Roads adjacent to the mainstem Green River in the Upper Green River sub-watershed are mainline roads that are expected to be permanently maintained throughout the foreseeable future. For these reasons, this habitat can never be expected to develop good LWD recruitment conditions.

CHANNEL MIGRATION ZONE

In moderate to high gradient contained reaches such as the Green River upstream of RM 88, the primary modes of LWD recruitment are windthrow and mass wasting. Unconfined channels, such as the mainstem Green River downstream of RM 88, generally occupy a CMZ. Wood is recruited to the river from throughout the CMZ via bank erosion as the channel slowly migrates across the floodplain or during rapid channel avulsion when new channels are cut through existing stands of vegetation. Large, unconfined Floodplain channels also receive LWD from upstream reaches. To date, there have been few investigations of the proportion of wood generated on-site versus from upstream in unconfined floodplain-type channels. However, as a general rule, the contribution of LWD from upstream reaches would be expected to increase as the contributing drainage area increased.

The draft Upper Green/Sunday Watershed Analysis is the only source of information on the current vegetation communities of the channel migration zone in the Upper Green River sub-watershed. The Floodplain segment between RM 84 and RM 88 has an associated CMZ that is approximately 300 feet wide. The CMZ in this reach currently supports sparse to dense stands of small deciduous trees. Because the CMZ represents the area from which most LWD will be recruited via bank erosion in the near future, LWD recruitment in this reach is generally rated poor. The CMZ is bordered by stands of young to mature coniferous and mixed coniferous and deciduous trees.

No information was available on the channel migration zone downstream of RM 84. The valley widens below RM 84 and it is assumed that the CMZ width increases. Most of the 300-foot wide riparian reserves mapped and characterized by the USFS Watershed Analysis are therefore probably located within the CMZ.

MICROCLIMATE

According to the studies reviewed by Knutsen and Naef (1997), dense stands of mature vegetation at least 200 feet wide are required to produce microclimate conditions that would be rated good. It is unknown whether the minimum riparian zone width required to maintain microclimatic conditions adjacent to large alluvial rivers would be substantially greater than 200 feet or whether microclimate conditions that differ substantially from the surrounding uplands even develop in such situations.

Assuming that the width required to maintain microclimate conditions cited by Knutsen and Naef (1997) are relevant to the mainstem Green River, none of the stands along the mainstem Green River in the Upper Green River sub-watershed provide good microclimate. The reason is that the existing stands consist primarily of small to medium sized trees. As with LWD, existing small and medium sized stands of trees will eventually develop conditions that could provide good microclimate if they are not subject to disturbance. However, the 12 miles of habitat in that is seasonally inundated or truncated by roads can never be expected to develop good microclimate conditions.

MIDDLE GREEN RIVER SUB-WATERSHED (RM 32 TO RM 64.5)

HISTORICAL CONDITIONS

A map of vegetation types produced by the U.S. Geological Survey (USGS) in 1894 depicts the Green River valley between RM 32 and RM 47 as "burnt areas not restocking." This suggests that historically the valley was forested and logged by early settlers. Based on the fact that the Middle Green River between RM 32 and RM 47 was laterally-mobile Floodplain channel type with braided sections, it is likely that the historic riparian vegetation community was comprised of a mix of species and age types. Young, early successional deciduous species such as willow, red alder, and black cottonwood probably occupied recently exposed bar surfaces, with older stands of coniferous or mixed coniferous and deciduous trees growing on terraces or stable floodplain surfaces. Western redcedar and Douglas-fir were reportedly the most common indigenous forest species in the Green River Valley (Wharton 1990). Other riparian tree species found in the Middle Green River valley downstream of the Green River gorge probably included black cottonwood, bigleaf maple, Sitka spruce, and western hemlock.

Little specific information is available on historic vegetation types in the gorge and upstream to RM 64.5. The downstream end of the gorge is mapped as “burnt areas restocking” on the 1894 USGS Land Classification Map. Based on channel type, it is assumed that laterally-stable moderate to high gradient contained reaches such as the Green River gorge and the section of river between RM 61 and RM 64.5 supported dense stands of coniferous trees including Douglas-fir, western redcedar, and western hemlock. Riparian communities associated with unconfined reaches such as the channel segment between RM 58 and RM 61 probably supported vegetation similar to that downstream of the Green River gorge.

CURRENT CONDITIONS

Current riparian conditions in the middle Green River sub-watershed were assessed using a combination of previously completed maps of riparian communities and direct aerial photo interpretation. In 1996, King County compiled detailed maps of existing vegetation types within a 300-foot wide band along each side of the mainstem Green River from RM 32 to RM 45. Tree-size and density in deciduous or coniferous communities depicted on these maps was estimated using 1:7920 scale color aerial photos taken in 1992. Vegetation stands within 300 feet of either side of the mainstem Green River between RM 47 and RM 64.5 were delineated on black and white orthophoto quads dating from 1999.

Riparian conditions in the Middle Green River sub-watershed vary in direct relation to the channel types described in Chapter 2.3 (Hydromodification). The riparian zone within the reach between HHD and Tacoma’s Headworks (RM 61 to RM 64.5) is forested, but frequently truncated by roads or railroads, as the narrow valley bottom historically provided the easiest access route to the Upper sub-watershed. The unconfined Floodplain channel segment between RM 58 and RM 61 is also forested, but the vegetation stands immediately adjacent to the channel are composed primarily of small deciduous trees that became established on formerly active bar surfaces and channel margins following initiation of flood control at HHD in 1964. Most of the riparian zone associated with the Large Contained channel type known as the Green River gorge (RM 45 to RM 57) is intact and composed of large, mixed coniferous and deciduous trees because the steep, rocky canyon walls make forest harvest and development difficult. Agricultural development and flood control structures (levees and revetments) have altered the riparian community somewhat in the wide valley associated with the Floodplain channel type between RM 32 and RM 45. However, riverside parks (including Metzler-O’Grady Park RM 38.5 to RM 40; and Flaming Geyser Park RM 43 to RM 45) and steep bluffs the river impinges on in several locations still support largely intact stands of small to medium sized deciduous trees and mixed coniferous and deciduous forest.

Cumulatively, approximately 84 percent of the riparian zone along the mainstem Green River in the Middle Green River sub-watershed still supports stands of native deciduous or coniferous forest (Figure RIP-4). However, only 53 percent of the Middle Green River has an intact riparian zone at least 300 feet wide. According to the NMFS criteria for riparian function, with the exception of the Green River gorge, riparian zones in the Middle Green River sub-watershed are currently not functioning properly because most are too narrow or support non-native vegetation (bare ground, grass, shrubs or development).

BANK STABILITY

Riparian communities with a width less than that sufficient to maintain bank stability (i.e., ≤50 feet in width) comprise approximately 24 percent of the banks in the Middle Green River sub-watershed. However, in many cases, where the riparian zone consists of a narrow strip of shrubs or trees, levees provide artificial bank stability. Levees and revetments affect approximately 40 percent of the channel between RM 31 and RM 45, primarily at the downstream end of that reach (Chapter 2.3).

Bank stability is currently rated good in all three channel segments located upstream of the Green River gorge. In the floodplain channel segment downstream of the Green River gorge (RM 32 to RM 45), notable areas of bank erosion occur where agricultural fields are located immediately adjacent to the right bank near RM 36, RM 37.2, and RM 38.3, and on the left bank near RM 39.6. Large landslides have resulted in bare, eroding banks near RM 36 and RM 42.3. Elsewhere, riparian conditions are generally sufficient to maintain fair to good bank stability (Figure RIP-4).

SHADE

For most of its length, the mainstem Green River in the Middle Green sub-watershed is a wide, shallow river with little riparian shade. Upstream of the Green River gorge (elevation 800 feet to 1,000 feet MSL), the target shade required to maintain water temperatures at or below 16 ^{o}C is 70 percent (WFPB 1997). The bankfull channel width is approximately 120 feet in this reach, indicating that riparian trees at least 103 feet tall are required to provide shade to the entire river channel (Figure RIP-2). Evaluation of aerial photos taken in 1987 suggests that the current riparian stand provides approximately 40 percent shade in this reach. Conditions may have improved somewhat since 1987, but shade is still probably only fair in this reach.

Within the Green River gorge (RM 45 to RM 58), shade is currently in good condition based on tree species, size, and the width of the existing riparian zone. In addition, the steep sideslopes provide topographic shade in this segment.

Downstream of the Green River gorge between RM 32 and RM 45 (elevation 50 to 220 feet MSL), the target shade to maintain stream temperature of 16^{o}C is 90 percent (WFPB 1997). Although the majority of this reach (64 percent) had good shade conditions based on the vegetation classification and width (Table RIP-3), the actual shade provided to the stream channel is probably lower than the target shade. Evaluation of aerial photographs taken in 1992 indicated that the existing riparian stand provides approximately 20 to 40 percent shade along most of this reach, well below the target amount.

ORGANIC MATTER AND TERRESTRIAL INVERTEBRATE RECRUITMENT

Based on width and vegetation, existing riparian conditions provide for good organic matter (OM) and terrestrial invertebrate recruitment along approximately 40 percent of the mainstem Green River in the Middle Green River sub-watershed (Table RIP-5). Areas where the existing riparian zone is not sufficiently wide to maintain OM and terrestrial insect inputs occur primarily where agricultural fields are located directly adjacent to the channel or on bar surfaces that are just being colonized by perennial riparian vegetation. The distribution of habitat conditions along the mainstem in this sub-watershed with respect to organic matter recruitment is similar to that described above for shade.

SEDIMENT FILTRATION

Approximately 40 percent of the mainstem riparian habitat in the Middle Green River sub-watershed is sufficient to provide good sediment filtration. Riparian areas that rated fair for sediment filtration generally support dense shrub or tree communities but are too narrow to completely filter sediment from overland flows. Between RM 64.5 and RM 61, sediment filtration is considered poor because gravel roads within the riparian zone restrict the width to less than 75 feet in many areas and serves as a source of increased fine sediment delivery. Riparian conditions currently meet the width and vegetation type requirements for good sediment filtration in the upper Floodplain channel type (RM 58 to RM 61) and the Green River gorge (RM 45 to RM 58). Downstream of the Green River gorge (RM 32 to RM 45), locations where sediment filtration is rated poor occur primarily where farm fields or residences occupy sites directly adjacent to the river or where the riparian community is composed of sparse stands of small trees that are in the process of colonizing former bar surfaces (Figure RIP-4).

LARGE WOODY DEBRIS RECRUITMENT

Riparian stands provide good LWD recruitment along approximately 26 percent of the banks in the Middle Green River sub-watershed (Table RIP-5). The potential for recruitment of LWD is currently poor in the channel segment upstream of Tacoma's Headworks (RM 61 to RM 64.5). Riparian stands in that segment are truncated by stream-adjacent road and railroad right of ways, which have reduced LWD recruitment and will prevent recovery of recruitment as long as they remain in place.

Between the upstream end of the gorge (RM 58) and RM 61, LWD recruitment is currently rated fair. In general, the width of the riparian zone in this segment is sufficient to provide LWD, but the existing vegetation stands are currently composed of small to medium sized trees that are not yet large enough to act as functional LWD or key pieces in the Green River (Figure RIP-4). Between RM 58 and RM 61, the channel formerly migrated back and forth across the floodplain. This channel was straightened prior to 1953 (Chapter 2.3), and formerly active bars and islands have become fixed in place by encroachment of riparian vegetation as a result of flood control by HHD (Perkins 1993). In combination, these changes in geomorphic processes have likely substantially reduced in-situ LWD recruitment in this reach. In addition, HHD blocks the downstream movement of wood from the upper watershed, further reducing LWD recruitment to the Middle Green River.

Recruitment of LWD within the Green River gorge (RM 45 to RM 58) is generally rated good. With few exceptions, the riparian zone is intact (300 feet wide) and supports native vegetation (Figure RIP-4). Trees in the riparian zone are large, and along this reach include a substantial number of conifers.

The potential for recruitment of LWD downstream of the Green River gorge is currently highly variable (Figure RIP-4). The riparian zone is generally intact in Flaming Geyser and Metzler O'Grady Parks (located at RM 42 to RM 45 and RM 38 to RM 40, respectively), but the trees there are currently too small to provide functional or key-sized pieces of LWD. Most of the riparian zone in the Middle Green River sub-watershed that is rated poor (narrow width of small trees and shrubs) occurs where agriculture or residential development extends to the stream bank or where the riparian zone consists of formerly active gravel bar surfaces that are being successfully colonized by shrubs and small deciduous trees as a result of flood control by HHD.

Downstream of the Green River gorge, between RM 38 and RM 45, the river generally remains unconstrained and recruitment of LWD from bank erosion and channel migration can still occur. However, establishment of shrubs and young deciduous trees on formerly active bar surfaces suggests that flood control by HHD has reduced the rate of channel migration, thereby suppressing the recruitment of LWD. Downstream of RM 38, much of the river is artificially confined between levees (Chapter 2.3) that prevent channel migration and bank erosion, effectively halting natural recruitment of LWD.

CHANNEL MIGRATION ZONE

From RM 64.5 to approximately RM 61, the mainstem Green River is tightly confined between steep sideslopes and effectively has no channel migration zone. Between RM 57 and RM 61, the valley width increases to approximately 1500 feet across, and the Green River appears to have formerly had a channel migration zone that covered the entire valley floor. Transportation routes constructed through the valley adjacent to the channel in this reach cut off the river from much of its former channel migration zone. The earliest available aerial photos reveal that two large former meander bends had been disconnected from the river as early as 1942 (Chapter 2.3). Since that time, the channel planform has not changed dramatically and the function of the channel migration zone essentially has been lost in this channel segment. Downstream of RM 58, the mainstem enters the Green River gorge and has no channel migration zone until it emerges around RM 45.

The Middle Green River between RM 32 and RM 45 historically had a very active channel migration zone. Based on a map of former channel locations from 1906 to 1992, the width of the channel migration zone in this reach historically ranged from 300 to 2500 feet wide (Perkins 1993). Since human settlement, levees, stream adjacent roads, and the reduced frequency of floods have reduced the width of the channel migration zone by 75 to 90 percent (Perkins 1993). In addition, much of the remaining channel migration zone has been converted to agricultural or residential landuses and no longer supports native riparian vegetation.

MICROCLIMATE

Microclimate conditions are currently poor along most (52 percent) of the Middle Green River. Stands of small deciduous trees and shrubs or artificially narrow riparian zones downstream of the Green River gorge account for the majority of riparian habitat classified as poor. Microclimates within the Green River gorge are currently considered to be in good condition. Because the riparian zone is still largely intact, stands within the Metzler O'Grady Park area also in good condition, or on a trajectory to develop good microclimate conditions within the next few decades as medium size trees mature.

LOWER GREEN RIVER SUB-WATERSHED (RM 11 TO RM 32)

HISTORICAL CONDITIONS

The historical vegetation map produced by the U.S. Geological Survey (USGS) in 1894 depicts the Green River valley between RM 11 and RM 32 primarily as “cut areas not restocking.” There are also patches of ground mapped as “cut areas restocking” near Auburn. This suggests that historically the valley was timbered. Historically, the lower Green underwent a gradual transition from a gravel-bedded Floodplain channel type to a highly sinuous silt and sand bedded Palustrine channel type between RM 32 to RM 11 (Chapter 2.3). Soils data and anecdotal accounts suggest that the historic riparian vegetation community was comprised of a mix of coniferous-dominated riparian stands, forested wetlands, and swampy meadows (Wharton 1990; Dunne and Dietrich 1978; Mullineaux 1970; Pence 1946). Young, early successional deciduous trees such as willow, red alder, and black cottonwood probably occupied recently exposed bar surfaces, with older stands of coniferous or mixed coniferous and deciduous trees growing on terraces or stable floodplain surfaces. Western redcedar and Sitka spruce may have dominated forested wetlands. Other riparian tree species that were found in the lower Green River valley probably included black cottonwood, bigleaf maple, and western hemlock.

CURRENT CONDITIONS

Current riparian conditions in the Lower Green River sub-watershed were assessed using detailed maps provided by King County that depict existing vegetation and cover types within a 300-foot wide band along each side of the mainstem Green River from RM 11 to RM 32 (Figure RIP-5). Tree-size and density in deciduous or coniferous communities was estimated using 1:660 scale color aerial photos taken in 1992 where available.

Cumulatively, there is less than one mile of intact riparian zone comprised of medium to large mixed deciduous and coniferous trees along the lower mainstem Green. This area is located on the right bank near RM 32. Approximately 18 percent (12.4 miles) of the riparian zone in the Lower Green River sub-watershed supports native deciduous trees; however in most cases deciduous stands are narrow (<100 feet) or comprised of sparse young trees mixed with patches of grass, pavement, or bare ground (Figure RIP-5). Almost 50 percent of the riparian zone is comprised of forbs and grass, or shrubs, many of which are non-native (Chapter 2.6). Pavement and bare ground account for approximately 33 percent of the total area within 300 feet of the river. None of the mainstem riparian habitat in the Lower Green River sub-watershed is in good condition (Table RIP-6) or is considered to be functioning properly based on the NMFS criteria.

BANK STABILITY

While there are some areas of riparian vegetation that have a width and vegetation type sufficient to maintain good bank stability, over 80 percent of the banks in the Lower Green River are comprised of levees or revetments (Chapter 2.3). These structures artificially maintain bank stability and prevent erosion. Erosion control structures prevent many natural geomorphic processes from occurring, such as LWD recruitment or formation of undercut banks, both of which provide important habitat for salmonids. In addition, construction of artificial channel constraints has effectively eliminated the channel migration zone. Therefore existing riparian stands were not evaluated with respect to bank stability in this sub-watershed.

SHADE

Only 3 percent of the riparian stands along the lower mainstem Green River consist of vegetation communities that are considered to provide good riparian shade (Table RIP-6). The majority of the channel between RM 11 and RM 32 is exposed to direct solar radiation and has poor shade; the presence of roads and development within the floodplain will effectively prevent establishment of riparian vegetation that could provide adequate shade in the future. However, there are approximately five miles of riparian zone that currently supports stands of shrubs or small deciduous trees that are wide enough to provide adequate shade and could eventually develop good shade conditions in the future if left undisturbed. The majority of riparian zone where shade could develop in the future is located between RM 26 and 28 (Figure RIP-5).

ORGANIC MATTER AND TERRESTRIAL INVERTEBRATE RECRUITMENT

Existing riparian conditions provide for good organic matter (OM) and terrestrial invertebrate recruitment along only 3 percent of the mainstem Green River in the Lower Green River sub-watershed. Areas dominated by pavement, bare ground, or grass are not expected to ever provide good OM and terrestrial insect recruitment. However, if left undisturbed, shrub and young deciduous communities between RM 26 and 28 could eventually provide better OM and terrestrial invertebrate recruitment to the river if trees are established and allowed to mature.

SEDIMENT FILTRATION

The presence of roads, pavement, and developed areas within 300 feet of the stream severely restricts the effectiveness of sediment filtration in riparian zones in the Lower Green River sub-watershed. Only 1.8 miles of habitat presently provides good sediment filtration (Table RIP-6). An additional 5.9 miles provide fair sediment filtration, but in general the presence of contributing activities near the stream will prevent future improvements in sediment filtration by riparian zones.

LARGE WOODY DEBRIS RECRUITMENT

None of the riparian habitat in the lower Green River provides good LWD recruitment (Table RIP-6). Approximately one mile of habitat on the right bank between RM 31 and RM 32 currently supports a mixed stand of medium-sized trees that could eventually grow to a size sufficient to serve as key or functional large woody debris. Portions of the area between RM 31 and RM 32 are confined by levees. In general, however, the channel is more mobile here than elsewhere in the Lower Green River sub-watershed. Steep sideslopes also may contribute LWD via mass wasting from outside of the 300-foot riparian zone in this area.

Recruitment of large woody debris from the remainder of the Lower Green River sub-watershed is currently considered poor and will continue to be limited by the activities near the stream that prevent development of mature forests and by artificial bank protection structures that prevent bank erosion and channel migration. These are the mechanisms by which most LWD is recruited in Floodplain and Palustrine channel types.

CHANNEL MIGRATION ZONE

Levees had been constructed along the mainstem Green in the Lower Green River sub-watershed at the time the earliest maps of the river channel were produced in 1907. Consequently, it is difficult to evaluate the historic extent of the channel migration zone in this sub-watershed. However, old meander scars suggest the channel had access to the entire valley bottom at some time in the past and the channel migration zone likely encompassed the whole area (Chapter 2.3). Over 90 percent of the channel in this sub-watershed is currently confined between levees or revetments, and the channel planform has changed little since 1907. Consequently, there is now effectively no channel migration zone associated with the river in the lower Green River sub-watershed (Chapter 2.3).

MICROCLIMATE

Microclimate conditions are currently rated as poor along almost all (97 percent) of the lower mainstem Green River. As for LWD recruitment, the area on the right bank between RM 31 and 32 provides the only remaining intact riparian stand, which will eventually provide functional microclimate if allowed to develop into a mature forest. Land use activities within the remainder of the riparian zone will continue to preclude development of forest stands required to provide good microclimate conditions.

GREEN/DUWAMISH ESTUARY (RM 0 TO RM 11)

HISTORICAL CONDITION

Riparian conditions along the Duwamish River are vastly different today from their condition in 1850. In the historical condition, approximately 1,230 acres of freshwater forested wetlands were found along the river (Blomberg et al. 1988). These areas, which were only inundated by flood events, likely included Sitka spruce (*Picea sitchensis*), willow (*Salix* spp.), red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), roses (*Rosa* spp.), and Douglas spirea (*Spirea douglasii*) (Tanner 1991).

Approximately 1,170 acres of tidal marshes occupied areas between +8 feet to +11 feet Mean Low Low Water (MLLW) (Blomberg et al. 1988). These areas were likely vegetated by bullrush (*Scirpus maritimus* and *S. americanus*), Lyngby's sedge (*Carex lyngbyei*), and sea arrow grass (*Triglochin maritimum*) (Tanner 1991). Vegetation found higher in the marsh probably included tufted hairgrass (*Deschampsia caepitosa*), saltgrass (*Distichlis spicata*), pickleweed (*Salicornia virginica*), Baltic rush (*Juncus balticus*), silverweed (*Potentilla pacifica*), and red fescue (*Festuca rubra*) (Dethier 1990).

Prior to settlement, approximately 1,450 acres of intertidal flats and shallows occupied areas below +6 to +8 feet MLLW. Although devoid of macrophytes, small patches of eelgrass (*Zostera marina*) or the green alga *Ulva* may have been present (Tanner 1991). The intertidal flats and shallows were concentrated at the mouth of the estuary bordering the south margin of Elliott Bay

(Blomberg et al. 1988). Approximately 440 acres of mostly unvegetated medium-depth water was also present between MLLW and -15 feet; this area too represents important feeding and refuge habitat for juvenile salmonids during low tide.

By 1940, filling of low-lying areas had eliminated virtually all of the fringing riparian surge plain forested wetland (termed tidal swamps in Blomberg et al. 1988) or isolated it from the river. In addition, Blomberg et al. estimated that 98 percent of the pre-contact tidal marsh, mud flats, and shallows had been eliminated by dredging and filling, with most of this loss coming by 1940 (Table RIP-8). The majority of the near-natural estuarine habitats that remained were at Kellogg Island, which itself has been altered by disposal of dredged materials (Grette and Salo 1986). Small areas of *Carex*-dominated marsh, generally under one acre in size and widely dispersed, and the unvegetated intertidal benches adjacent to the channel or along the river banks, are all that remained. LWD delivery to the estuary was greatly reduced by loss of riparian forests locally, upstream, and by debris removal to aid navigation. Consequently, habitat complexity, as well as area, was greatly reduced. Blomberg et al. (1988) calculated that in 1986 only 45 acres of tidal marshes and mudflats remained.

Blomberg et al. (1988) estimated that the pristine Duwamish Estuary had about 93,000 linear feet of channel shorelines supporting riparian vegetation below the location of the oxbows (present RM 7). Only a very small proportion of that shoreline retains a semblance of the natural sequence of shallow mudflat, sloping up to a saltmarsh bench, transitioning into freshwater marsh and riparian forest. The upper bank along the majority of the shoreline has been hardened with riprap or vertical bulkheads and little natural vegetation remains.

CURRENT CONDITIONS

Several data sources were used to determine the present condition of riparian zones in the Duwamish Estuary and Elliott Bay. The upper Duwamish Estuary from RM 11.0 to RM 5.3 was traversed by canoe in May 1999 and shoreline habitats noted and later mapped. For the lower estuary, between RM 5.3 and the mouth, habitat and substrate data collected by the Port of Seattle were used to characterize the riparian zone (Port of Seattle unpublished data). In Elliott Bay, the primary data used to characterize riparian habitat were aerial photos (Port of Seattle 1993) with limited ground truthing conducted during a field reconnaissance in May 2000. King County mapped riparian conditions along the Duwamish River from aerial photos dating from 1992 (Figure RIP-6).

A majority of the shoreline along the upper reaches of the Duwamish River is densely vegetated, typically by shrubs (Figures RIP-7 and RIP-8). Riprapped shorelines and levees are often overgrown with this shrub community, which is usually dominated by willows (*Salix* spp.) and non-native blackberries (*Rubus* spp.; e.g., Figure RIP-8). These shrubs provide some cover and shade, overhanging the water at middle and higher water levels, and may provide litter and insect production to the aquatic system. The total length of shoreline shrub cover between RM 11.0 and RM 5.3 is approximately 45,140 linear feet or 75 percent of the shoreline (Table RIP-9).

Trees taller than about 25 feet are most abundant along the Duwamish River shoreline in the reach between RM 8.0 and RM 7.0 (e.g., Figure RIP-7), forming a continuous line along the west bank and portions of the east bank. Trees are somewhat less dense upstream and considerably less dense downstream of this reach. The majority of larger trees are black cottonwood (*Populus trichocarpa*), bigleaf maple (*Acer macrophyllum*), and red alder (*Alnus rubra*). These species also provide shade and litter and insect fallout to the aquatic system. They also occasionally fall into the river and provide the additional functions of LWD.

The total length of shorelines with tree cover between RM 11.0 and the Turning Basin (RM 5.3) is approximately 21,340 linear feet or approximately 35 percent of the shorelines (Table RIP-9). Downstream of the Turning Basin, trees are very sparse except on, and adjacent to, Kellogg Island. Except for Kellogg Island, trees in the riparian zone are largely absent between RM 5.3 and RM 0.0 (Figure RIP-6). Few areas of upper bank (about 5 percent) between RM 11.0 and the Turning Basin are grass-lined (Figure RIP-9). A small area along the right bank at RM 6.3 is grass lined. Grass lines the left bank between RM 7.8 and RM 8.1 and the right bank at RM 8.5. Two small sections of left bank are grass-lined near RM 12.2. The total length of grass cover between RM 11.0 and RM 5.3 is approximately 3,130 linear feet (Table RIP-9).

The shoreline along Elliott Bay is dominated by overwater structures and industrial, urban, and residential development. The only areas of substantial riparian vegetation are found along Magnolia Bluff, at the southern portion of the Discovery Park property. Approximately 3,870 linear feet of undeveloped bluff is vegetated with deciduous trees and shrubs. South of Discovery Park, interrupted stands of trees and shrubs predominate in a residential bluff and beach community for approximately 11,010 linear feet. Immediately south of Magnolia Bluff lies a large marina and breakwater (Elliott Bay Marina) and two large overwater structures (Piers 90 and 91). South of these structures lies approximately 6,600 linear feet of riprap and grass cover along Myrtle Edwards Park. South of the park, over-water structures, seawalls, and industrial uses dominate the shore through downtown Seattle and Harbor Island. Seawalls, riprap, residential development, and intermittent grassy areas characterize the riparian zone west of Harbor Island to Duwamish Head. From Duwamish Head to Alki Point very little riparian vegetation is present, replaced with riprap, seawalls and a street running along the beach.

BANK STABILITY

Bank stability in the lower Duwamish below RM 11.0 is very similar to that found in the lower Green River between RM 11 and 32. Over 80 percent of the banks of the Duwamish Estuary are comprised of riprap, bulkheads, and levees (Chapter 2.3, Hydromodification). These structures artificially maintain bank stability and prevent erosion. However, erosion-control structures may prevent many natural geomorphic processes from occurring, such as LWD recruitment or the formation of undercut banks, both of which provide important habitat for salmonids. In addition, the construction of artificial channel constraints has effectively eliminated the channel migration zone. Therefore existing riparian stands were not evaluated with respect to bank stability in the estuary.

SHADE

Although much of the shore in the lower Duwamish below RM 11.0 is composed of artificial erosion-control structures, many of these structures are overgrown with dense shrubs or have tree stands immediately behind them. Between RM 11.0 and the Turning Basin (RM 5.3), approximately 35 percent of the shoreline is lined with large trees, although only sometimes are tree stands greater than 75 feet in width. Based on the width and vegetation type criteria provided in Table RIP-3, this portion of the shoreline provides 35.4 percent fair and 64.6 percent poor riparian shade (Table RIP-7). (Note that categorizations of riparian functions as good, fair, or poor based on criteria applicable to upper subbasins may not be fully relevant in the estuary and nearshore.) About 75 percent of this reach is lined with shrubs that provide nearshore shading for juvenile salmonids but do not provide significant temperature refuge, given the large width of the river.

Below the Turning Basin to the mouth, trees greater than 25 feet in height are very sparse, and shrubs line about 28 percent of the shore. Less than one percent of the river below the Turning Basin falls provides fair to good riparian shade. Most of this is on Kellogg Island and the adjacent secondary shore behind the island (RM 1.5 to RM 1.0; Table RIP-7).

Along the shore of Elliott Bay, large trees predominate only in undeveloped and less developed areas of Magnolia Bluff. Approximately 6,270 linear feet, or 6.3 percent of the shore, contain trees of a height and width to provide good riparian shading. Approximately 7,563 linear feet, or 7.5 percent of the shore, would provide fair riparian shading were it not for the southern exposure of this shoreline. Riparian vegetation along the remainder of Elliott Bay shore from West Point to Alki Point provides poor riparian shading (Table RIP-7). Substantial shoreline areas are shaded by buildings and overwater structures, however.

ORGANIC MATTER AND TERRESTRIAL INVERTEBRATE RECRUITMENT

Between RM 11.0 and RM 5.3 in the upper Duwamish River, over 35 percent of the shore is composed of trees, but only about 11.6 percent of the upper river has a riparian zone greater than 50 feet in width. Approximately 7,000 linear feet of shore between RM 7.0 and RM 8.0 has riparian tree habitat that provides fair to good organic matter (OM) and terrestrial invertebrate recruitment (Table RIP-7).

Below the Turning Basin, trees are sparse except for approximately 5,088 linear feet of shoreline on Kellogg Island and the adjacent shore, which has a riparian zone that provides fair to good organic matter and invertebrate recruitment. This represents about 6.1 percent of the shore between RM 5.3 and RM 0 (Table RIP-7). Limited areas of brackish marsh vegetation along the shoreline supplement riparian function of shrubs and trees. Marsh vegetation provides a source of organic matter to the estuary and insects that may be directly preyed upon by juvenile salmonids. As with riparian shading, the recruitment of organic matter and terrestrial invertebrates along Elliott Bay occurs primarily in the Magnolia Bluff area. Approximately 7.4 percent of shore provides good recruitment and 6.3 percent provides fair recruitment based on the criteria used in the upper river. The remainder of the Elliott Bay shore is poor in the recruitment of organic matter and terrestrial invertebrates because of sparse vegetation (Table RIP-7).

SEDIMENT FILTRATION

As previously described, much of the upper Duwamish Estuary (RM 11.0 to RM 5.3) is lined with shrubs, trees, or grass but rarely is the riparian zone wide enough to provide substantial riparian functions except for shading. Approximately 11.6 percent of the shore in the upper Duwamish Estuary has a riparian corridor between 75 and 150 feet in width, which can provide fair sediment filtration. Below the Turning Basin, trees are sparse except for approximately 5,088 linear feet of shoreline on Kellogg Island and the adjacent shore, which has a riparian zone that provides fair to good sediment filtration. This represents about 6.1 percent of the shore between RM 5.3 and RM 0 (Table RIP-7).

Much of the Magnolia Bluff area contains trees and shrubs that provides sediment filtration; however, this function is irrelevant given that the bluff itself is a major source of sediment that feeds the coastal drift cell from the Smith Cover Marina to West Point. Approximately 6,270 linear feet, or 6.3 percent of the shore, supports trees and shrubs at a width that provides good sediment filtration. About 7,563 linear feet, or 7.5 percent of the Elliott Bay shore, is vegetated with shrubs and small trees to at least 75 feet in width, and provides fair sediment filtration. The remainder of the Elliott Bay shore would likely provide poor sediment filtration (Table RIP-7).

LARGE WOODY DEBRIS RECRUITMENT

Most of the tree-lined riparian zone of the upper Duwamish, from RM 11 to the Turning Basin, is less than 100 feet in width, so it would be categorized as providing poor recruitment of LWD. About 7,000 linear feet between RM 8.0 and RM 7.0, or 11.6 percent of shoreline, has riparian trees of the size and extent to provide fair recruitment of LWD (e.g., Figure RIP-8). About 9.5 pieces of LWD per mile were observed during a recent habitat survey in the upper Duwamish, but much of this appeared weathered and probably came from historical upstream sources (e.g., Figure RIP-10). Below the Turning Basin, trees are sparse except for approximately 3,639 linear feet of shoreline on Kellogg Island, which has a riparian zone that provides good organic LWD recruitment. This represents about 4.4 percent of the shore between RM 5.3 and RM 0.

LWD recruitment in Elliott Bay is considered good at 6.3 percent of the shore and fair at 7.5 percent of the shore, all within the Magnolia Bluff region (Table RIP-7). During field observations in May 2000, several areas of the bluff had contributed large numbers of recently fallen trees to the upper intertidal zone. All other areas provide no recruitment of LWD because of a lack of trees.

MICROCLIMATE

Microclimate conditions are currently poor throughout the Duwamish River riparian zone. There was no direct information regarding microclimate and the effects on salmonids readily available for incorporation into this report.

MAJOR TRIBUTARIES

SOOS CREEK (RM 0 – RM 13)

HISTORICAL CONDITION

No information was located that described historical riparian conditions along mainstem Soos Creek. In general, it is likely that vegetation in the Soos Creek watershed was similar to that found elsewhere in the Puget Sound region. There were numerous small ponds and lakes in the upland areas that form the headwaters of Soos Creek. Soils and geology maps suggest there also were numerous wetlands in the upper Soos Creek basin (Mullineaux 1970; King County 1989). These areas were probably characterized by a mixture of emergent wetlands or wet meadows intermixed with forested wetlands and uplands supporting Douglas-fir on the dryer sites. The canyon reach (RM 2 to RM 5) most likely supported a dense stand of coniferous trees. Vegetation would have been similar to that described for the Middle Green River where Soos Creek leaves the canyon and flows across the Green River floodplain before joining the mainstem.

CURRENT CONDITIONS

Little mature native vegetation remains in the riparian zone along mainstem Soos Creek. There is still an intact riparian zone supporting native tree species between RM 1.5 to RM 2.8, and patches of native deciduous trees also occur elsewhere along the lower six miles of the Creek (Figure RIP-4). However, these trees are generally small. The remainder of the riparian zone is composed primarily of shrubs or grass. Development and roads limit the riparian zone width in many cases.

Bank Stability. Because riparian communities along Soos Creek are composed primarily of shrubs or small trees, none of the stream system is considered to have good bank stability (Table RIP-10). Areas such as the reach between RM 1.5 and RM 3 that now support stands of small deciduous trees or mixed coniferous and deciduous trees are considered to be in fair condition and will attain good condition if allowed to mature.

Shade. Like bank stability, shade is considered to be in good condition only where there are dense stands of medium or large trees. The Soos Creek channel was generally visible on aerial photos, indicating that existing shade levels are less than 40 percent; the target shade to maintain temperatures below 16 ^{o}C at this elevation ranges from 80 to 90 percent (WFPB 1997). None of the riparian habitat along Soos Creek is considered to provide good shade at the present time (Table RIP-10), although good shade could develop in the 4.5 miles of riparian habitat currently rated fair if the area remains undisturbed. Development precludes achievement of good shade conditions along the remainder of Soos Creek. In particular, cleared areas adjacent to the channel downstream of RM 1.5 and powerline corridors that parallel the stream upstream of RM 6 prohibit development of mature riparian vegetation.

Organic Matter and Terrestrial Invertebrate Recruitment. Current riparian condition along Soos Creek with respect to organic matter (OM) and terrestrial insect recruitment is similar to conditions described for shade. Recruitment of OM and insects are currently fair within the young deciduous stand located between RM 1.5 and RM 3.0. Elsewhere the lack of tall, mature trees limits the supply of OM and terrestrial insects delivered to Soos Creek.

Sediment Filtration. As noted previously, dense stands of young trees or shrubs are sufficient to provide good sediment filtration where the riparian zone is at least 150 feet wide. Approximately 45 percent of the existing riparian zone along Soos Creek provides good sediment filtration (Table RIP-10). Elsewhere roads, development, or other contributing activities near the stream reduce the ability of riparian area to filter fine sediment.

Large Woody Debris Recruitment. Because existing stands of riparian trees (where present) are small, LWD recruitment is currently considered poor all along Soos Creek (Table RIP-10). As the riparian stand between RM 1.5 and 2.8 matures, it will begin to provide functional LWD. However, wood recruitment along the remainder of Soos Creek is expected to remain low, as landuse activities effectively preclude the development of mature riparian stands.

Channel Migration Zone. Delineation of the channel migration zone associated with smaller streams such as Soos Creek requires field data. Consequently, channel migration zone conditions in Soos Creek were not assessed for this report.

Microclimate. Microclimate conditions are also currently poor throughout the Soos Creek riparian zone (Table RIP-10). As with LWD, when the riparian stand between RM 1.5 and 2.8 matures, it will begin to provide good microclimate conditions. However, the microclimate along the remainder of Soos Creek is expected to remain in poor condition, because existing landuse activities effectively preclude the development of mature riparian stands wide enough to provide good microclimate.

NEWAUKUM CREEK (RM 0-RM 12)

HISTORICAL CONDITION

No information was located that described historic vegetation patterns in the Newaukum Creek basin. In general, it is likely that vegetation there was similar to that elsewhere in the Puget Sound. Newaukum Creek originates in the Cascade foothills east of Enumclaw. Vegetation in this areas consists primarily of Douglas-fir and western Hemlock, with western redcedar and various deciduous species occurring along streams. The middle portion of Newaukum Creek (RM 3 to RM 9) flows across the Osceola mudflow deposit (Mullineaux 1970). Like the headwaters of Soos Creek, a geologic map of that area suggest there were numerous wetlands (Mullineaux 1970). These areas were likely characterized by a mixture of wet meadows or forested wetlands, while drier areas probably supported Douglas-fir. The canyon reach (RM 2 to RM 5) probably supported a dense stand of coniferous trees.

CURRENT CONDITIONS

The riparian assessment of Newaukum Creek covered only the areas downstream of RM 10. Much of the middle portion of the basin has been developed for agriculture. Little mature native vegetation remains along Newaukum Creek between RM 3 and RM 10. There is an intact riparian zone supporting native tree species from RM 3 to the confluence with the Green River. There are also intact riparian zones covered by shrubs or small trees between RM 6.7 and RM 7 and on the left bank between RM 7.5 and 8.2. These represent locations where functional riparian zones could develop in the future if they remain undisturbed. None of the riparian zone along Newaukum Creek is currently considered to be in good condition (Figure RIP-4) or functioning properly according to the NMFS criteria. However, there is approximately 6.8 miles of habitat that is currently in fair condition and that will develop into good riparian habitat if allowed to mature. Most of this habitat is located in the canyon between RM 0 and RM 3. There are also stands of dense young deciduous trees between RM 6.7 and RM 7 and along the left bank from RM 7.5 to RM 8.2 that could develop into good riparian habitat in the future.

Bank Stability. Overall, almost 40 percent of the stream banks along Newaukum Creek support riparian vegetation sufficient to maintain bank stability (Table RIP-10). An additional 8 percent (1.5 miles) is currently in fair condition. However, extensive agricultural development in the valley between RM 3 and RM 9 has substantially impacted bank stability; 53 percent of the habitat overall is in poor condition, and conditions are not expected to improve in those reaches unless native riparian vegetation is restored.

Shade, The canyon Newaukum Creek has cut through the bluff adjoining the mainstem Green River provides the best remaining riparian habitat along the mainstem of Newaukum Creek. Shade is currently good in this reach (RM 0.1 to RM 3). Shade is considered poor along the remainder of Newaukum Creek upstream of RM 3.

Organic Matter and Terrestrial Invertebrate Recruitment. The current condition of riparian zones with respect to organic matter (OM) and terrestrial insect recruitment are similar to conditions described for shade. Recruitment of OM and insects are currently good within the mixed stand of medium sized trees located between RM 0.1 and RM 3.0. Elsewhere the lack of tall, mature trees limits the supply of OM and terrestrial insects delivered to Newaukum Creek.

Sediment Filtration. Sediment filtration is rated good in 47 percent of the existing riparian habitat along Newaukum Creek (Table RIP-10). Elsewhere agricultural development has substantially reduced the ability of the riparian zone to filter sediment.

Large Woody Debris Recruitment. LWD recruitment is currently in fair condition along lower Newaukum Creek (RM 0.1 to RM 0.3). As the riparian stand matures, it will begin to provide functional LWD. Stands of young deciduous trees are also present between RM 6.7 and RM 7.0 and on the left bank from RM 7.5 to RM 8.2. These stands could serve as a source of LWD recruitment in the future if they are protected and allowed to mature. Wood recruitment along the remainder of Newaukum Creek is expected to remain low, as landuse activities effectively preclude the development of mature riparian stands.

Channel Migration Zone. Delineation of the channel migration zone associated with smaller streams such as Newaukum Creek requires field data. Consequently, channel migration zone conditions in Newaukum Creek were not assessed for this report.

Microclimate. Microclimate is currently in poor condition in 67 percent of the riparian habitat along Newaukum Creek, where trees have been removed and existing vegetation consists of grass or shrubs. As for LWD, when the riparian stand between RM 0.1 and 3.0 matures, it will begin to provide good microclimate conditions. However, the microclimate along the remainder of Soos Creek is expected to remain in poor condition, as landuse activities effectively preclude the development of mature riparian stands.

LIST OF TABLES

Table RIP-1. Range and average widths required to maintain proper riparian function as reported in the literature (after Knutsen and Naef 1997).

Table RIP-2. Parameters used to characterize the current condition of riparian zones along the mainstem Green River (after WFPB 1997)

Table RIP-3. Criteria used to evaluate riparian function along the mainstem Green River.

Table RIP-4. Summary of riparian condition functional status in the Upper Green River sub-watershed, RM 64.5 to RM 84.

Table RIP-5. Summary of riparian condition functional status in the Middle Green River sub-watershed, RM 32 to RM 64.5

Table RIP-6. Summary of riparian condition functional status in the Lower Green River sub-watershed, RM 11 to RM 32.

Table RIP-7. Summary of riparian condition functional status in the Duwamish Estuary and Elliott Bay.

Table RIP-8. The Duwamish Estuary habitat changes from 1854 to 1986 (after Blomberg et al. 1988).

Table RIP-9. Elliott Bay/Duwamish Estuary riparian habitat (Pentec Field Survey 1999; Port of Seattle unpublished data).

Table RIP-10. Summary of riparian condition functional status in the Major Tributaries to the Green River.

LIST OF FIGURES

Figure RIP-1. Generalized curves indicating the effectiveness of four riparian functions in relation to the distance from the edge of the stream channel (Source: FEMAT 1993).

Figure RIP-2. Height of trees required to provide shade in large rivers (Source: WFPB 1997).

Figure RIP-3. Existing riparian conditions along the mainstem Green River in the Upper Green River sub-watershed.

Figure RIP-4. Existing riparian conditions along the mainstem Green River in the Middle Green River sub-watershed.

Figure RIP-5. Riparian cover types along the mainstem Green River in the Lower Green River sub-watershed (Source: King County GIS).

Figure RIP-6. Riparian cover types along the mainstem Green River in the Green/Duwamish Estuary (Source: King County GIS)

Figure RIP-7. Tree cover along the Duwamish River at RM 7.5 (along 42nd Ave S). (Pentec Field Survey 1999)

Figure RIP-8. Shrub cover along the Duwamish River at RM 9.8 (Pentec Field Survey 1999).

Figure RIP-9. Grass cover along the Green River at RM 12 (Pentec Field Survey 1999).

Figure RIP-10. LWD along the Duwamish River at RM 5.5 (Pentec Field Survey 1999).

Table RIP-1. Range and average widths required to maintain proper riparian function as reported in the literature (after Knutsen and Naef 1997).		
Riparian Function	**Range of Reported Widths (Ft)**	**Average of Reported Width (Ft)**
Bank Stability	34-44	38
Shade	31-151	90
Organic Matter Recruitment	50-75	NA
Sediment Filtration	26-300	138
Large Woody Debris Recruitment	100-200	147
M icroclimate	200-525	287
NA=Not applicable		

Table RIP-2. Parameters used to characterize the current condition of riparian zones along the mainstem Green River (after WFPB 1997).	
Parameter	**Values**
Cover Type	Bare/Pavement Grass/Forb Shrub Deciduous tree Coniferous tree Mixed deciduous and coniferous tree
Size (tree only)	Small (<12 inches dbh) Medium (12 to 20 inches dbh) Large (>20 inches dbh)
Density	Sparse (>33 percent bare ground visible on aerial photo) Dense (<33 percent bare ground visible on aerial photo)

Table RIP-3. Criteria used to evaluate riparian function along the mainstem Green River.						
	Width			**Vegetation**		
Function	**Good**	**Fair**	**Poor**	**Good**	**Fair**	**Poor**
Bank Stability	≥50	25-50	<25	Dense Med/Lg trees	Dense small trees	Sparse trees, shrub, grass or bare
OM/Terrestrial Insect inputs	>75	50-75	<50	Dense Med/Lg trees	Dense small trees	Sparse trees, shrub, grass or bare
Shade	≥100	75-100	<75	Dense Med/Lg trees (mainstem) Dense trees (tributaries)	Dense small trees (mainstem) Dense shrubs (tributaries)	Sparse trees, shrub, grass or bare
Sediment filtration	≥150	75-150	<75	Dense trees or shrubs	Dense trees or shrub; or contributing activities 200-300 ft	Sparse trees, grass, bare; or contributing activities within 200 feet
LWD	≥150	100-150	<100	Large, dense, conifer, deciduous or mixed (mainstem) Medium to large, dense conifer or mixed (tributaries	Medium, dense deciduous; sparse, large conifer or mixed	Sparse medium of large trees, small trees, shrub, grass or paved
Microclimate	≥300	200-300	<200	Dense large trees	Dense medium trees	Sparse or young trees; shrub, grass or paved

Table RIP-4. Summary of riparian condition functional status in the Upper Green River sub-watershed, RM 64.5 TO 84[1].				
Function	**Good (miles/percent)**	**Fair (miles/percent)**	**Poor (miles/percent)**	**Comment**
Bank Stability	21.6 (50%)	7.2 (17%)	14.0 (33%)	Raw eroding banks or slides at RM 32.5, 36.1, 37.5, 39-40, RM 43, and 44
Shade	0 (0%)	21.6 (51%)	21.2 (49%)	Based on criteria table; actual shade is naturally low due to channel width
OM/terrestrial invertebrate recruitment	21.6 (51%)	6.1 (14%)	15.1 (35%)	
Sediment Filtration	26.8 (63%)	0.9 (2%)	15.1(35%)	
LWD recruitment	0 (0%)	21.6 (51%)	21.2 (49%)	Majority of properly functioning located within gorge and Metzler O'Grady Park
Micro-climate	0 (0%)	21.1 (49%)	21.7 (51%)	
[1]Data for RM 64.5 to RM 76 from USFS watershed analysis GIS data; Data for RM 76 to RM 84 from Lester Watershed Analysis.				

Table RIP-5. Summary of riparian condition functional status in the Middle Green River subwatershed.				
Function	**Good (miles/percent)**	**Fair (miles/percent)**	**Poor (miles/percent))**	**Comment**
Bank Stability	40.05 (64%)	6.95 (11%)	15.4 (24%)	Raw eroding banks or slides at RM 32.5, 36.1, 37.5, 39-40, RM 43, and 44
Shade	39.45 (63%)	4.85 (8%)	18.1 (29%)	Based on criteria table; actual shade is naturally low due to channel width
OM/terrestrial invertebrate recruitment	40.05 (64%)	5.35 (9%)	17.2 (27%)	
Sediment Filtration	40.80 (65%)	7.25 (12%)	14.35 (23%)	
LWD recruitment	22.6 (36%)	16.35 (26%)	23.45 (38%)	Majority of properly functioning located within gorge and Metzler O'Grady Park
Micro-climate	18.2 (29%)	11.65 (19%)	32.55 (52%)	

Table RIP-6. Summary of riparian condition functional status in the Lower Green River subwatershed.				
Function	**Good (miles/percent)**	**Fair (miles/percent)**	**Poor (miles/percent)**	**Comments**
Bank Stability	NA	NA	NA	Actual bank stability driven by levees/revetments
Shade	1.1 (3%)	5.0 (12%)	35.9 (85%)	
OM/terrestrial invertebrate recruitment	1.1 (3%)	5.0 (12%)	35.9 (85%)	
Sediment Filtration	1.8 (4%)	5.9 (14%)	34.3 (82%)	Greater functional habitat because shrubs and young trees provide filtration
LWD recruitment	0	1.1 (3%)	40.9 (97%)	
Micro-climate	0	1.1 (3%)	40.9 (97%)	

Table RIP-7. Summary of riparian condition functional status in the Duwamish Estuary and Elliott Bay.				
Function	**Good (miles/[%])**	**Fair (miles/[%])**	**Poor (miles/[%])**	**Comment**
Duwamish River RM 11.0 – 5.3 (both banks)				
Bank stability	NA	NA	NA	Actual bank stability driven by levees/revetments
Shade	0	4.0 (35.4)	7.4 (64.6)	Temperature moderation function less relevant in estuary than upstream
OM/terrestrial invertebrate recruitment	0	1.3 (11.6)	10.1 (88.4)	Invertebrate recruitment supplemented by tidal marsh vegetation in limited areas
Sediment filtration	0	1.3 (11.6)	10.1 (88.4)	Function in estuary less critical than in upstream areas
LWD recruitment	0	1.3 (11.6)	10.1 (88.4)	Function in estuary less critical than in upstream areas
Microclimate	0	0	0	Not relevant in estuary
Duwamish River RM 5.3 – mouth (both banks up to the East and West waterways)				
Bank stability	NA	NA	NA	Actual bank stability driven by levees/revetments
Shade	0.7 (4.4)	0.02 (1.7)	14.4 (93.9)	Temperature moderation function less relevant in estuary than upstream
OM/terrestrial invertebrate recruitment	0.7 (4.4)	0.02 (1.7)	14.4 (93.9)	Invertebrate recruitment supplemented by tidal marsh vegetation in limited areas
Sediment filtration	0.7 (4.4)	0.02 (1.7)	14.4 (93.9)	Function in estuary less critical than in upstream areas
LWD recruitment	0.7 (4.4)	0	14.6 (95.6)	Function in estuary less critical than in upstream areas
Microclimate	0.7 (4.4)	0	14.6 (95.6)	Not relevant in estuary
Elliott Bay – West Point to Alki Point (including the East and West waterways)				
Bank stability	NA	NA	NA	Actual bank stability driven by levees/revetments
Shade	1.2 (6.3)	1.4 (7.50)	16.4 (86.3)	Important primarily in potential surf smelt spawning areas
OM/terrestrial invertebrate recruitment	1.4 (7.5)	1.2 (6.3)	16.4 (86.3)	
Sediment filtration	1.2 (6.3)	1.4 (7.50)	16.4 (86.3)	Function in nearshore less important than in riverine areas
LWD recruitment	1.2 (6.3)	1.4 (7.50)	16.4 (86.3)	Function in nearshore less important than in riverine areas
Microclimate	0.5 (2.6)	0	18.6 (97.4)	Not relevant in estuary
Sediment supply/feeder bluffs	Unriprapped section of Magnolia to West Point	0	All the rest of shoreline	

Table RIP-8. The Duwamish Estuary habitat changes from 1854 to 1986 (Blomberg et al. 1988).					
	Year (percent change)				Cumulative Percent Change
Habitat Types	**1854**	**1908**	**1940**	**1986**	
Medium depth water (acres)	440	410 (-7%)	390 (-5%)	360 (-8%)	-18%
Shallows and flats (acres)	1,450	1,080 (-26%)	130 (-88%)	25 (-81%)	- 98%
Tidal marshes (acres)	1,170	970 (-17%)	160 (-84%)	20 (-88%)	- 98%
Tidal swamps (acres)	1,230	590 (-52%)	0	0	- 100%
Riparian shoreline (ft)	93,000	90,000 (-3%)	38,000 (-58%)	19,000 (-50%)	- 80%
Development Conditions					
Deep water (acres)	—	240	210 (-12%)		
Developed shorelands and floodplain (acres)	0	1,210	3,750 (+310%)	5,220 (+39%)	+430%
Developed shoreline (ft)	0	4,000	47,000 (+1175%)	53,000 (+12%)	+1,430%
New shoreline from fill (ft)	—	21,000	28,000 (+33%)	28,000	—

Table RIP-9. Elliott Bay/Duwamish Estuary riparian habitat (Pentec Field Survey 1999, Port of Seattle unpublished data).			
Riparian Zone	**Linear Ft**	**Miles**	**Percentage of Shoreline (both banks)**
Duwamish Estuary RM 11.0 to RM 5.3			
Trees	21,340	4.04	35.4
Shrubs	45,140	8.55	75
Grass	3,130	0.59	5.2
Duwamish Estuary RM 5.3 to RM 0.0			
Vegetated shoreline*	22,400	4,024	27.6
Elliott Bay – Don Armeni Park to Terminal 91			
Vegetated shoreline*	3,150	0.6	4.5
* Port of Seattle data were not broken into riparian type, but limited aerial photographs indicate that few trees are present.			

Table RIP-10. Summary of riparian condition functional status in the Major Tributaries to the Green River.				
Function	**Good (miles /(%))**	**Fair (miles /(%))**	**Poor (miles /(%))**	**Comment**
Soos Creek				
Bank Stability	0	7.0 (35)	13.0 (65)	
Shade	0	4.5 (22)	15.5 (78)	
OM/terrestrial invertebrate recruitment	0	4.5 (22)	15.5 (78)	
Sediment Filtration	9.12 (45)	2.35 (12)	8.5 (43)	
LWD recruitment	0	0	20 (100)	RMZ intact, but trees appear small from RM 1.5 to 2.8
Micro-climate	0	0	20 (100)	
Newaukum Creek				
Bank Stability	6.7 (39%)	1.35 (8%)	9.05 (53%)	
Shade	6.7 (39%)	1.35 (8%)	9.05 (53%)	
OM/terrestrial invertebrate recruitment	6.7 (39%)	1.35 (8%)	9.05 (53%)	
Sediment Filtration	8.05 (47%)	0	9.05 (53%)	
LWD recruitment	0	6.8 (40%)	10.4 (60%)	At risk in canyon because of tree size; small dense stands 6.7-7 and 8.4-8.9 patches with future potential
Micro-climate	0	5.7 (33%)	11.3 (67%)	

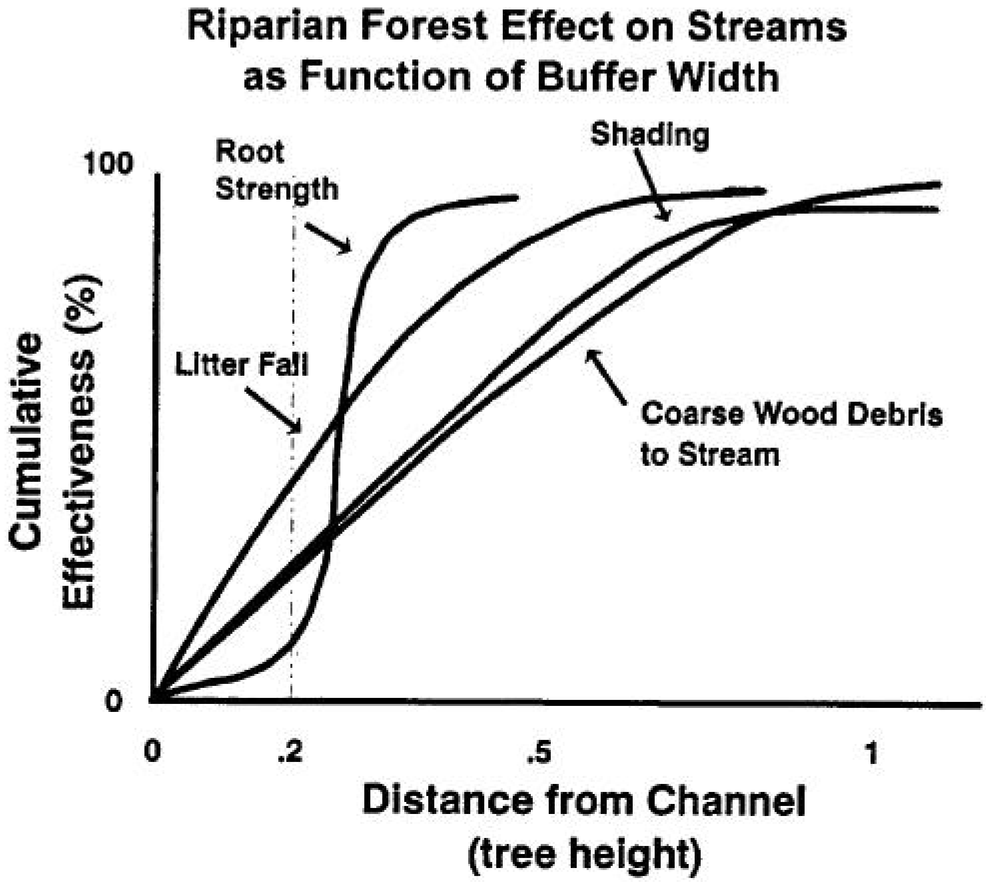
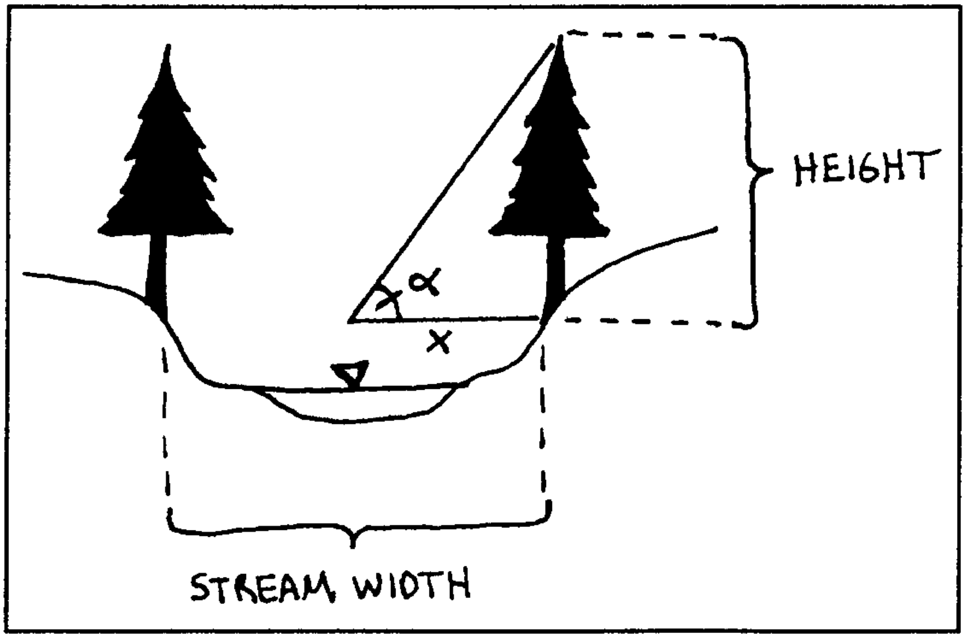


Figure RIP-1. Generalized curves indicating the effectiveness of four riparian functions in relation to the distance from the edge of the stream channel (Source: FEMAT 1993).

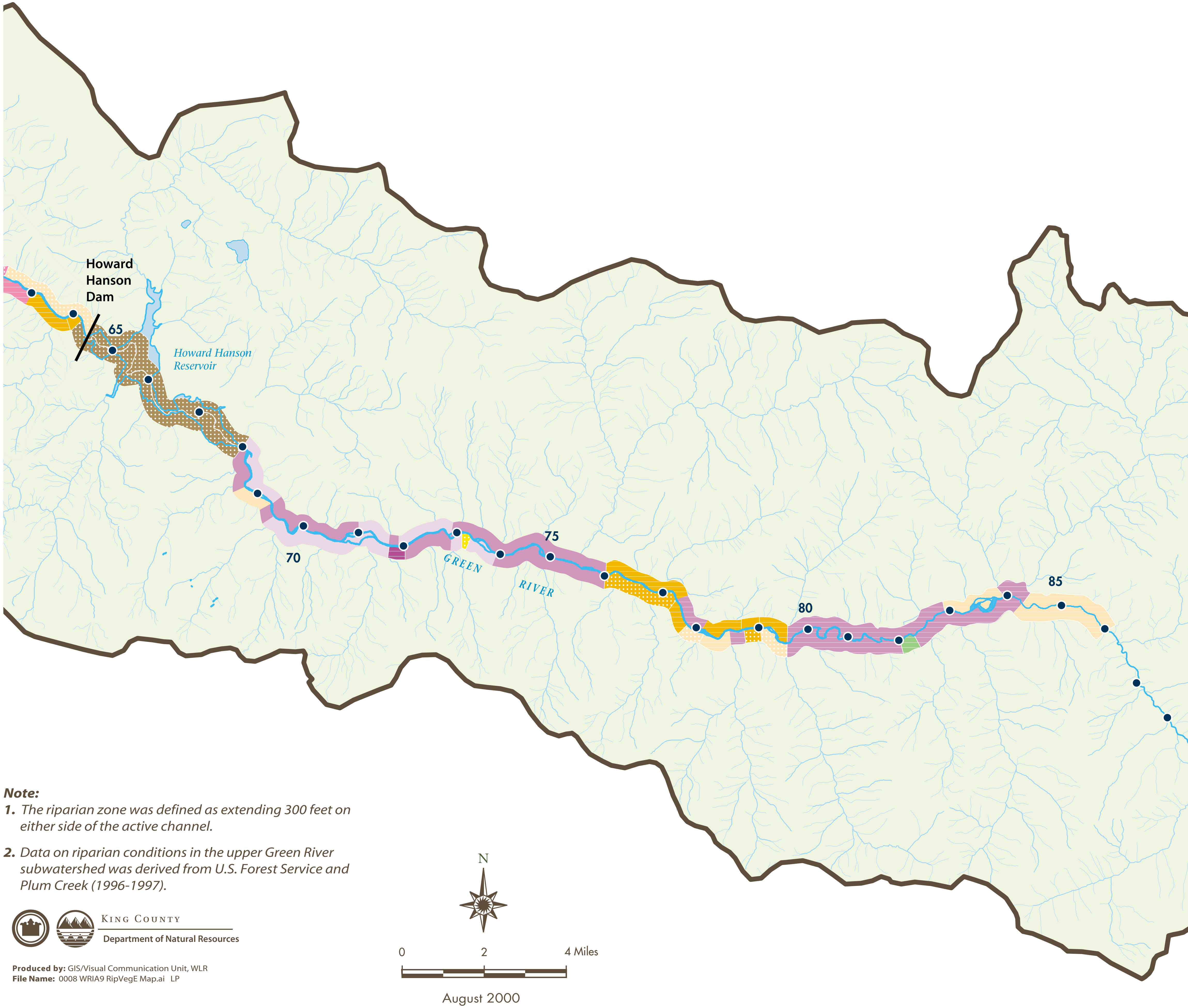


where: $\text{HEIGHT} = (\tan \alpha)X$

$X = ½ \text{ STREAM WIDTH}$

Figure RIP-2. Height of trees required to provide shade in large rivers (Source: WFPB 1997).

Figure RIP-3
Riparian Vegetation
Mainstem Green River
Upper Green River Subwatershed



River Mile and Number
Major Road
River
WRIA 9 Boundary
Open Water

VEGETATION TYPE:

Bare Ground, Pavement
Shrub
Grass, Forb, Field
Small Deciduous
Medium Deciduous
Large Deciduous
Small Mixed Conifer and Deciduous
Medium Mixed Conifer and Deciduous
Large Mixed Conifer and Deciduous
Medium Conifer

VEGETATION WIDTH:

50 Feet or Less
50-150 Feet
150-300 Feet

Note:

1. *The riparian zone was defined as extending 300 feet on either side of the active channel.*
2. *Data on riparian conditions in the upper Green River subwatershed was derived from U.S. Forest Service and Plum Creek (1996-1997).*

King County
Department of Natural Resources

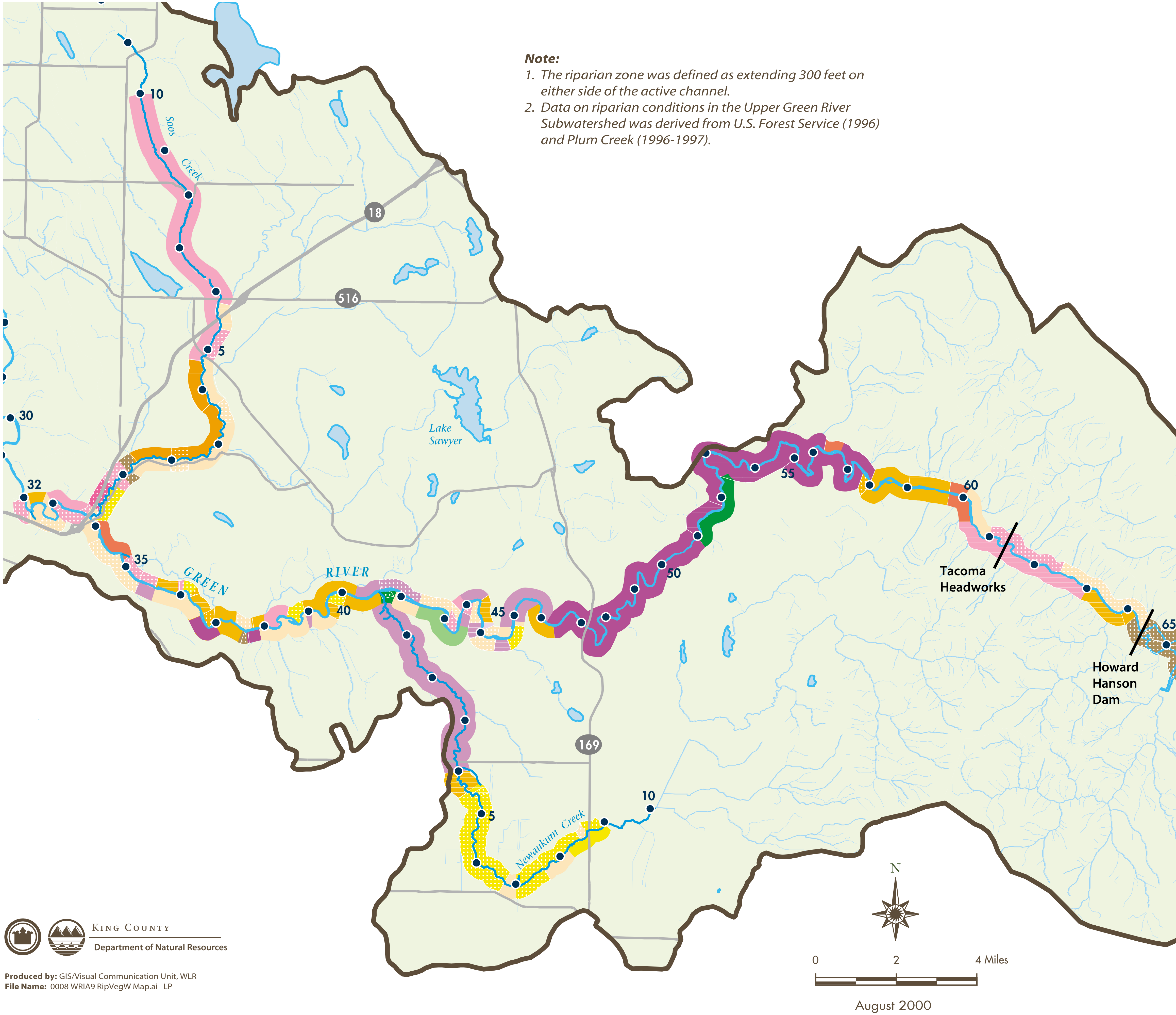
Produced by: GIS/Visual Communication Unit, WLR
File Name: 0008 WRIA9 RipVegE Map.ai LP

August 2000

Figure RIP-4

Riparian Vegetation

Mainstem Green River, Soos Creek and Newaukum Creek Middle Green River Subwatershed



• 60 River Mile and Number

Major Road

River

WRIA 9 Boundary

Open Water

VEGETATION TYPE:

Bare Ground, Pavement

Shrub

Grass, Forb, Field

Small Deciduous

Medium Deciduous

Large Deciduous

Small Mixed Conifer and Deciduous

Medium Mixed Conifer and Deciduous

Large Mixed Conifer and Deciduous

Medium Conifer

Large Conifer

VEGETATION WIDTH:

50 Feet or Less

50-150 Feet

150-300 Feet

King County

Department of Natural Resources

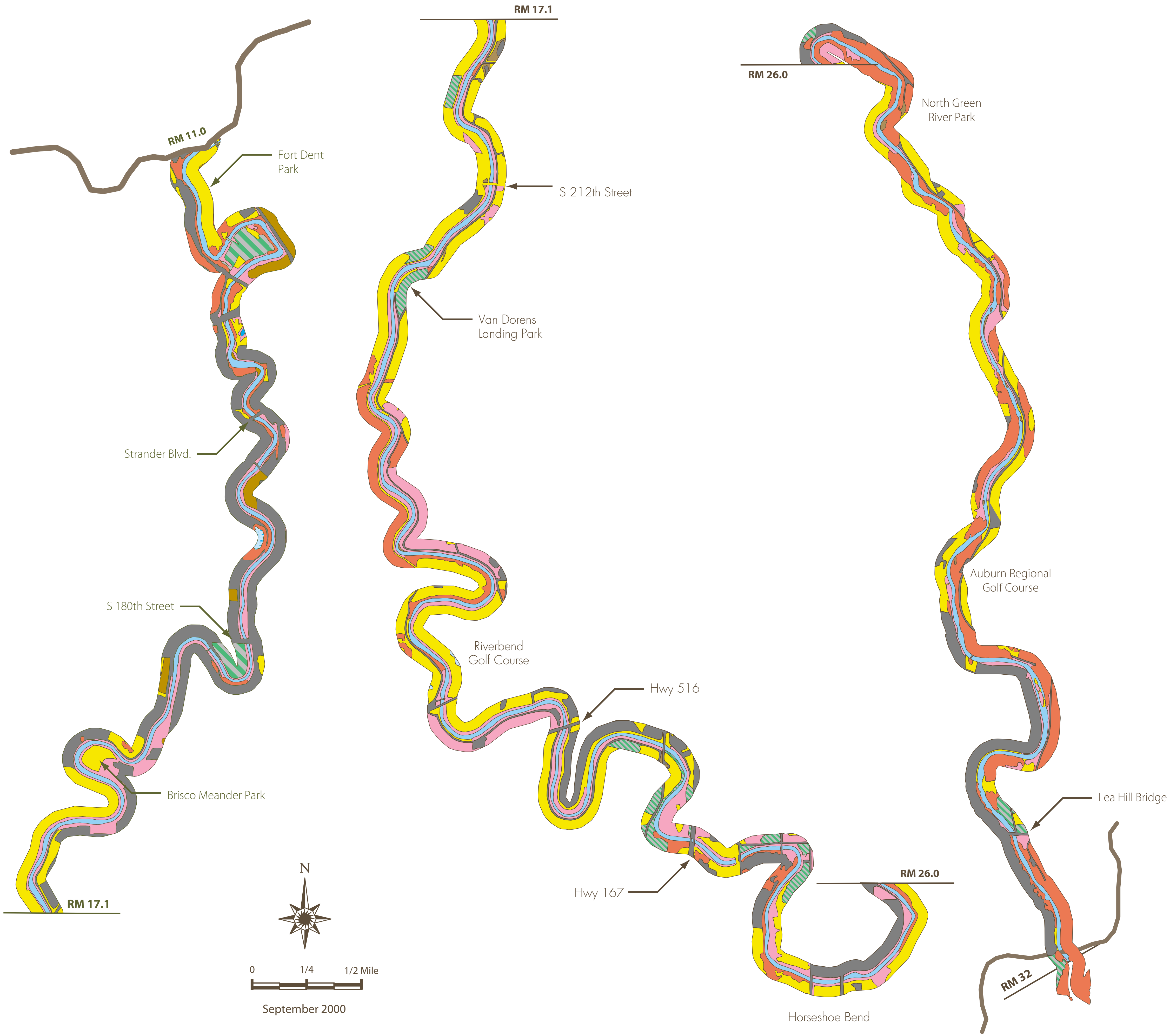
Produced by: GIS/Visual Communication Unit, WLR

File Name: 0008 WRIA9 RipVegW Map.ai LP

Figure RIP-5

1995 Riparian Cover Types

Lower Green River Subwatershed



DT - Deciduous Trees

S - Shrubs

F - Forbs and Grasses

B - Bare Ground

P - Pavement

M- Buildings, Pavement, Mixed Trees

I - Intertidal

WL - Wetland

W - Water

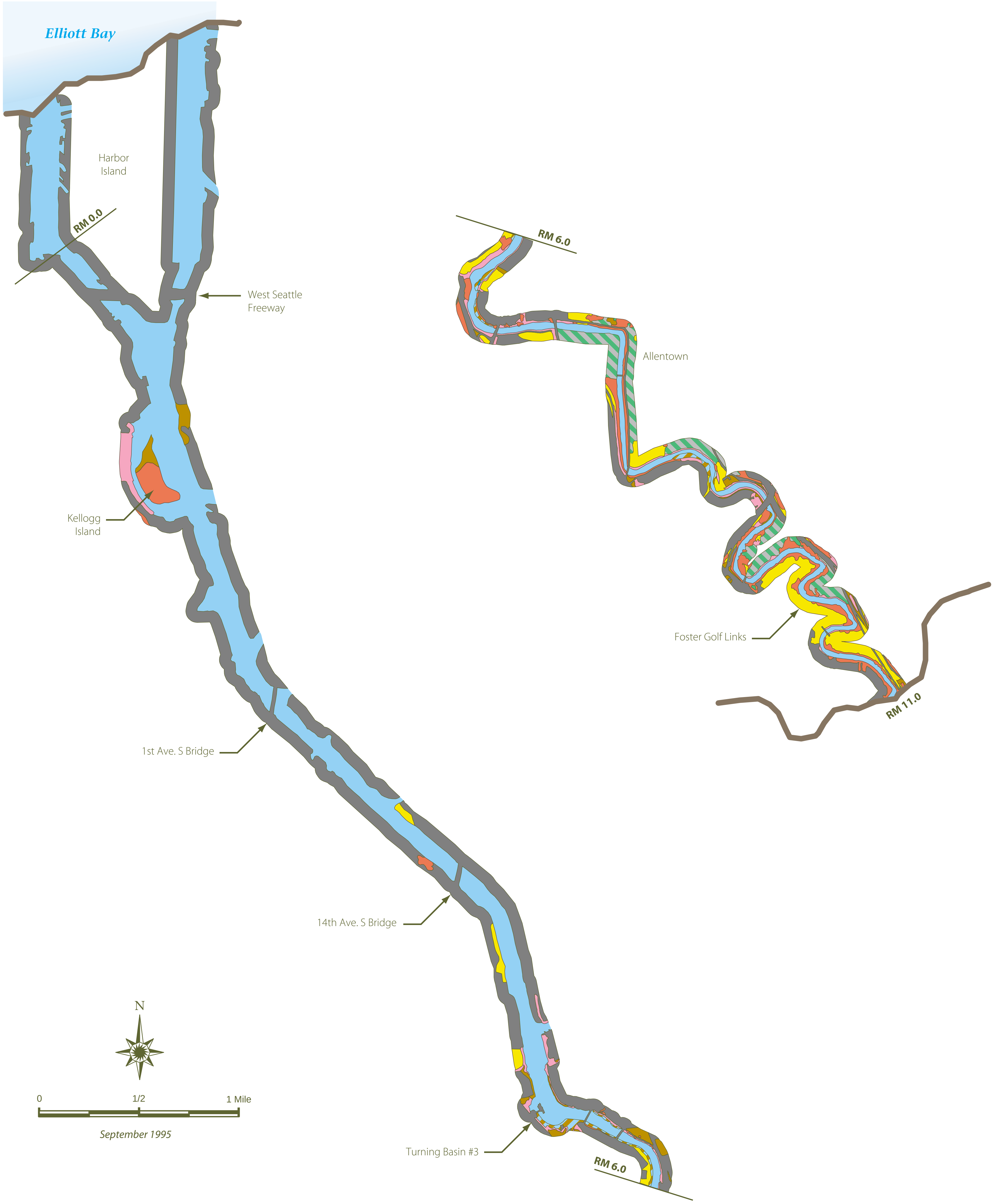
R - River

FODS Subwatershed Boundary

Note:
Vegetation mapped from 1 inch : 600 feet color aerial stereophotos from the King County Surface Water Management Middle Green River series taken by David C. Smith and Associates for creation of 2 foot contour topographic maps filmed in March, 1994.

Produced by: GIS/Visual Communication Unit, WLR
File Name: 0011 W9 GreenVeg95-1.ai LP

King County
Department of Natural Resources



DT - Deciduous Trees

S - Shrubs

F - Forbs and Grasses

B - Bare Ground

P - Pavement

M- Buildings, Pavement, Mixed Trees

I - Intertidal

WL - Wetland

W - Water

R - River

FODS Subwatershed Boundary

Note:

Vegetation mapped from1 inch:600 feet color aerial stereophotos from the King County Surface Water Management Middle Green River series taken by David C. Smith and Associates for creation of 2 foot contour topographic maps filmed in March,1994.

Produced by: GIS/Visual Communication Unit, WLR
File Name: 0008 WRIA9 GreenVeg95.ai LP

King County
Department of Natural Resources

Figure RIP-6

1995 Riparian Cover Types

Duwamish River

Figure RIP-7 Tree cover along the Duwamish River at RM 7.5 (along 42nd Avenue S).

Figure RIP-8 Shrub cover along the Duwamish River at RM 9.8.

Figure RIP-9 Grass cover along the Green River at RM 12.

Figure RIP-10 LWD along the Duwamish River at RM 5.5.

2.5 FISH PASSAGE

2.5 FISH PASSAGE

EXECUTIVE SUMMARY

There are no known natural impassable barriers in the mainstem Green River. The historic upstream extent of anadromous salmonid use is presumed to be to approximately RM 93 based on an analysis of gradient and a series of mapped cascades. The earliest documented anthropogenic barrier on the mainstem Green River was a wooden weir that was erected annually from 1904 to 1924 at the confluence of Soos Creek to allow capture of adult chinook in the mainstem.

Dams constructed in the Upper Green River sub-watershed have had the largest impact on the up and downstream passage of salmonids. The Tacoma Headworks, completed in 1913, was the first complete barrier to adult salmon and steelhead in the Green River, and it eliminated naturally reproducing anadromous fish production in the upper sub-watershed for 80 years. Howard Hanson Dam (HHD), constructed at RM 64.5 in 1962, also represents a complete barrier to the upstream passage of anadromous and resident fish.

Since 1982, between two and four million juvenile salmon and steelhead annually have been released upstream of HHD. In addition, in 1992, the Muckleshoot Indian Tribe (MIT), Tacoma, WDFW, and Trout Unlimited began cooperatively administering a temporary fish ladder and trap-and-haul program. Under the pilot program, between 7 and 133 adult steelhead annually have been captured in a temporary fish trap at the Headworks and either released upstream of HHD for natural spawning or used to produce fry for outplanting in the Upper Green River sub-watershed.

Downstream passage of juvenile salmonids also is interrupted by HHD. Current annual survival of juvenile salmon and steelhead migrating through HHD outlets is estimated to be between 5 and 25 percent based on a fish passage model and on-site monitoring data (Dilley and Wunderlich 1992, 1993). There are two main concerns regarding downstream fish passage associated with Howard Hanson Dam:passage through the dam, andpassage through the reservoir.

Studies conducted in the early 1990's indicated that the low survival rate of fish passing Howard Hanson Dam was primarily a function of two factors: 1) the spring refill operation strategy, which influences the ability of fish to locate the outlets; and 2) the low survival of juveniles passing through the bypass outlet pipe. Outmigrant studies indicate that there is little or no injury to juvenile fish using the radial gates, but injury rates through the bypass pipe ranges from 3 to almost 90 percent, depending on species and environmental conditions (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992; 1993).

Passage through the reservoir also is believed to negatively impact juvenile salmonids migrating downstream from the Upper Green River sub-watershed. Aitkin et al. (1996) found that migration of juvenile coho salmon through Howard Hanson Reservoir took a significantly longer time at both mid- and high-pool elevations. Travel times for both coho and steelhead smolts were longest at mid-pool. Travel time was more closely related to refill rate than pool level, increasing as refill rate increased. Survival of fish passing through the reservoir has been identified as a concern, but cannot be assessed using existing data.

Most fish migrating downstream past Tacoma's existing Headworks pass over the dam spillway, where there is a potential for fish to be injured. Although there is no site-specific information on the hydraulic conditions or injury or mortality of fish at the Tacoma Headworks, information from studies at other projects suggest that the rate of mortality experienced by juvenile fish passing over a 17-foot spillway is probably low (R2 1998; Seiler et al. 1992). The second avenue of passage available at the Headworks is the pipeline intake. The existing Headworks intake screens do not meet NMFS or State screen criteria and juvenile salmonids can potentially be impinged on the intake and killed; very small juvenile salmonids could pass through the existing screens.

Passage of fish in the mainstem Green River also is influenced by instream flows. Low flows in the Green River are most likely to adversely affect adult chinook salmon moving upstream in August and September when flows are generally lowest. Recent high levels of coarse sediment inputs upstream of HHD and alterations in the flow regime downstream of HHD have transformed sections of the mainstem channel from what is believed to have been predominantly a single-thread pool riffle channel morphology to a braided morphology consisting of numerous shallow flow paths. Mainstem low flow concerns have been documented in the middle Green River between RM 31 and RM 45 and in the upper Green River near RM 83. In addition, because of the porous nature of alluvial fans that form at tributary junctions, water flowing across the fans is rapidly lost to seepage, and flows may disappear before reaching the foot of the fan (Levin 1981). Recent increases in sediment delivery linked to land management activities, in conjunction with low levels of LWD and reduced streamflows, have exacerbated low flow concerns and may impede passage of adult salmonid. Low flow concerns have been identified at the confluence of the mainstem Green River and Newaukum Creek and in a number of tributaries in the Upper sub-watershed.

Subsurface flows have also been observed in the alluvial valley portion of the North Fork Green River during late summer (Noble 1969; Hickey 2000b) and could prevent salmonids from entering the river or moving upstream. Operation of the North Fork well field by Tacoma could reduce flows in the North Fork, although there is currently no data on the extent of this potential impact.

High temperatures are also believed to affect upstream fish passage. Temperatures that exceed the optimum range identified by NMFS have been observed throughout the watershed from the upstream end of Howard Hanson Reservoir to the estuary. Temperatures exceeding potentially lethal limits have been measured in the Lower Green River and Green/Duwamish Estuary. As late as 1985, kills of adult chinook were reported in the Green/Duwamish Estuary (LeVander 1999).

Passage concerns also have been identified on some of the larger tributaries. In 1958, an earthen dam was constructed on the Black River approximately 1,000 feet upstream of the confluence with the Green River. This blocked passage of anadromous fish into Springbrook Creek. In 1972, the U.S. Soil Conservation Service (SCS) replaced the dam with the Black River Pumping Station (BRPS). Although it is equipped with upstream and downstream passage facilities, the

BRPS still poses a barrier to the upstream and downstream movement of salmonids at certain seasons. The upstream passage facility is normally operated from mid-September through 31 January annually. The operational window likely precludes the upstream migration of some anadromous and resident cutthroat trout and steelhead, which migrate upstream in the spring.

The BRPS also has a downstream passage facility that is operated from early April to mid-June each year, for approximately eight hours per day, Monday through Friday. Fish attempting to move downstream outside of that operational window are either prevented from exiting the Springbrook system or must pass through the unscreened large pumps (if operational). Juvenile chinook emerge and begin moving downstream in the Middle Green River system and Soos Creek as early as February (Jeanes and Hilgert 2000). Consequently, early downstream migrants would be prevented from exiting the Springbrook system. The existing screens and their placement at the BRPS do not meet current NMFS screening criteria. Adult salmonids cannot pass downstream via the downstream fish passage facility at the BRPS. Chinook salmon have been known to move upstream and become trapped in the Springbrook Creek system, where there is little if any suitable chinook spawning habitat.

Finally, interactions between humans and fish during the period when adult salmon are moving upstream may affect reproduction success. Streamside recreation or fish viewing activities have been observed to reduce the rate of upstream coho migration in the Middle and Lower Green River (Malcom 1996). In-water activities such a canoeing also have been observed to displace adult coho salmon downstream (Malcom 1996). In addition to direct disturbances, mammalian odors, such as those arising from dogs and people, have been observed to temporarily disrupt and slow the upstream migration rate of adult coho and chinook salmon. Salmon will expend energy as they are displaced downstream and then must again expend energy to move back upstream. In portions of the river with elevated temperatures, the energy loss and stress has the potential to increase pre-spawn mortality and reproductive success. Displacement of salmon from redds may result in incomplete redd construction, selection of less preferred redd sites, and incomplete spawning.

KEY FINDINGS

- There are no known natural impassable barriers in the mainstem Green River up to RM 93. The historic upstream extent of anadromous salmonid use is presumed to have been around RM 93 based on an analysis of river gradient and a series of mapped cascades.

- The earliest documented anthropogenic barrier on the mainstem Green River was a wooden weir erected annually from 1904 to 1924 on the mainstem Green River at the confluence of Soos Creek to allow capture of adult chinook in the mainstem.

- The Tacoma Headworks, which began construction in 1911 and was finished in 1913, was the first permanently constructed barrier to adult salmon and steelhead in the Green River. This dam has blocked anadromous salmonids from natural migration and reproduction in the Upper Green River sub-watershed for nearly 90 years.

- Salmonids that are not naturally produced (e.g., hatchery planted juveniles), juveniles from adult steelhead that were transported upstream of the dams, and resident trout may migrate downstream past Tacoma's existing Headworks. Most pass over the dam spillway, where there is a potential for fish to be injured. The second avenue of passage available at the Headworks is the pipeline intake. The existing Headworks intake screens do not meet NMFS or State screen criteria (1/4" mesh size from center strand to center strand, with 5/32" openings) and juvenile salmonids can potentially be impinged on the intake and killed; very small juvenile salmonids could pass through the existing screens.

- Howard Hanson Dam completed construction in 1962 at RM 64.5 and represents another complete barrier to the upstream passage of anadromous and resident fish. There are two main concerns regarding downstream fish passage associated with Howard Hanson Dam:

  1. **Passage through the dam**. The low survival rate of fish passing through Howard Hanson Dam is primarily a function of two factors: 1) the spring refill operation strategy, which influences the ability of fish to locate the outlets; and 2) the low survival of juveniles passing through the bypass outlet pipe. Current annual survival of juvenile salmon and steelhead migrating through HHD outlets is estimated to be between 5 and 25 percent based on a fish passage model and on-site monitoring data (Dilley and Wunderlich 1992, 1993). Out-migrant studies indicate that there is little or no injury to juvenile fish using the radial gates (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992; 1993), but injury rates through the bypass pipe range from 3 to almost 90 percent, depending on species and environmental conditions.

  2. **Passage through the reservoir**. Aitkin et al. (1996) found that migration of juvenile coho salmon through Howard Hanson Reservoir took a significantly longer time at both mid- and high-pool elevations. Travel times for both coho and steelhead smolts were longest at mid-pool. Travel time was more closely related to refill rate than pool level, increasing as refill rate increased. Survival of fish passing through the reservoir has been identified as a concern but cannot be assessed using existing data.

- Recent high levels of coarse sediment inputs upstream of HHD and alterations in the flow regime downstream of HHD have transformed sections of floodplain channel types from essentially a single-thread pool riffle channel morphology to a braided morphology consisting of numerous shallow flow paths. These shallow paths are most likely to adversely affect juvenile coho and steelhead rearing in the mainstem and adult chinook salmon moving upstream in August and September when flows are generally lowest. Mainstem low flow concerns have been documented in the middle Green River between RM 31 and RM 45 and in the upper Green River near RM 83.

- Low flow concerns have been identified at the mouths of several of the Green River's tributaries, including Newaukum Creek and a number of streams in the Upper sub-watershed. This largely is due to the porous nature of alluvial fans. Water flowing across these fans is rapidly lost to seepage, and flows may disappear before reaching the foot of the fan (Levin 1981). An increase in channel sediment from logging in the Upper Green River sub-watershed, lower flows in the Middle Green River, and low levels of LWD in both reaches have exacerbated low flow concerns and may impede passage of adult salmonids.

- Subsurface flows have been observed in the North Fork Green River during late summer (Noble 1969; Hickey 2000b), and could prevent salmonids from entering the river or moving upstream. Operation of the North Fork well-field by Tacoma could reduce flows in the North Fork, although there currently are insufficient data on the extent of this potential impact.

- Water quality degradation can pose significant barriers to salmonid migration. Temperatures that exceed the optimum range identified by NMFS have been observed throughout the watershed from the upstream end of Howard Hanson Reservoir to the estuary. Temperatures exceeding potentially lethal limits have been measured in the lower Green River and Green/Duwamish estuary. As late as 1985, kills of adult chinook were reported in the Green/Duwamish estuary presumably from inadequate water quality parameter(s) that are not specified in this report

- In 1958, an earthen dam was constructed on the Black River, 1000 feet upstream from the Green River. Besides impeding salmonid migration into the Springbrook Creek system, this dam blocked flows from the Green River from backwatering into the remnant Black River, which could have provided some refuge habitat for salmonids during high flows. In 1972, the US Soil Conservation Service replaced the dam with the Black River Pumping Station (BRPS), which currently is operated by King County. Although it is equipped with upstream and downstream fish passage facilities, the BRPS can act as a barrier to migration of juvenile and adult salmonids due to inadequate screening, fishway design, and operation schedule.

- Adult salmonids cannot pass downstream via the downstream fish passage facility at the Black River Pumping Station. Chinook salmon have been known to move upstream and become trapped in the Springbrook Creek system, where there is little if any suitable chinook spawning habitat.

- Streamside recreation or fish viewing activities have been observed to reduce the rate of upstream coho migration in the Middle and Lower Green River (Malcom 1996). In-water activities such canoeing have also been observed to displace adult coho salmon downstream (Malcom 1996). In addition to direct disturbances, mammalian odors, such as those arising from dogs and people, have been observed to temporarily disrupt and slow the upstream migration rate of adult coho and chinook salmon. Salmon will expend energy as they are displaced downstream and then must again expend energy to move back upstream. In portions of the river with elevated temperatures, the energy loss and stress have the potential to increase pre-spawn mortality and reduce reproductive success. Displacement of salmon from redds may result in incomplete redd construction, selection of less preferred redd sites, and incomplete spawning.

DATA GAPS

There is limited information on the location of natural barriers or historical fish distribution, particularly for the Upper Green River sub-watershed:

- There is little information available to assess the historic impacts of operation of Tacoma's North Fork well field on fish passage in the North Fork Green River.

- The available information is inadequate to assess survival through Howard Hanson Reservoir.

- The rate of injury or mortality (if any) for fish passing the existing Tacoma Headworks is unknown.

- Data on fish passage barriers and other physical habitat in Newaukum and Soos Creeks is incomplete. This lack of physical habitat information is a WRIA-wide data gap for all tributary and mainstem reaches.

INTRODUCTION

Anadromous salmonids require passage between the ocean where the fish grow and mature to their natal streams where adult fish spawn, eggs incubate, and juvenile fish rear for a period of weeks to years. Resident fishes such as bull trout often reside in mainstem or large tributary channels, migrating upstream to spawn in small headwater streams or lakes. Upstream and downstream fish passage is influenced by physical impediments such as natural waterfalls, dams, or culverts; by hydrologic factors that influence variations in the flow regime; and by biological factors such as predation or behavioral responses to disturbances.

Natural physical barriers within the Green River Watershed include waterfalls, steep gradient cascades, or tributary channels that become too small or steep to support fish. The most common anthropogenic physical barriers in most watersheds are those associated with road crossings. Culverts installed to pass flow beneath roads my have perched outlets that exceed the leaping ability of some species. Other passage concerns frequently identified at culverts are high velocities, shallow flows, or steep gradients. Debris or sediment that collects at the culvert inlet may also interfere with or prevent up and downstream passage. Other anthropogenic physical barriers in the Green River Watershed include dams that have been constructed for flood control, water diversion, or other purposes.

Up and downstream migration of salmonids also is affected by hydrologic conditions. Naturally occurring low flows act to delay fish from moving into some tributary channels until flows are great enough to support successful spawning. Species that utilize shallow, low gradient tributaries that may be susceptible to low flows or adverse water quality conditions, such as chum and coho, have developed life histories such that upstream migration is timed to occur in seasons when flows are higher. Other species, such as steelhead and coastal cutthroat trout, which prefer steep, high gradient headwater channels, spawn in the spring when high flows that frequently scour the beds of such channels are less likely to occur. Water use and dams alter hydrologic conditions, interfering with upstream and downstream fish passage through reduced streamflows or lower flow velocities.

Finally, biological factors also can interfere with the upstream and downstream movement of fish. Adverse water quality conditions (e.g., high temperatures or low dissolved oxygen levels) may cause fish to avoid certain areas or delay their upstream migrations until conditions improve. Concentrations of predators caused by changes in habitat or riparian characteristics may prey on juvenile fish as they move downstream. Disturbances by recreational users or activities taking place on the stream banks may temporarily displace fish or increase stress levels and energy expenditure.

The following sections describe upstream and downsteam passage concerns in the mainstem Green River and larger tributaries (Soos, Newaukum and Springbrook creeks). Passage concerns on tributary streams are discussed further in Chapter 3.

UPPER GREEN RIVER (RM 64.5 TO RM 93)

PHYSICAL BARRIERS

NATURAL BARRIERS AND IMPEDIMENTS

There is only limited observational data of the most upstream extent of use by anadromous fish in the Upper Green River sub-watershed. Since the release of adult fish into the Upper Green River sub-watershed was initiated in 1980, winter steelhead have been observed spawning in the mainstem Green River as far upstream as RM 83 (Cropp 1999). The presumed historic upstream extent of use by chinook, steelhead, and coho was estimated by identifying the location at which the channel gradient steepened to over 12 percent, at approximately RM 91.8 (Cutler 2000). Numerous researchers have demonstrated a strong linkage between habitat features, gradient, and fish use (Montgomery et al. 1999; Benda et al. 1992; Kozel et al. 1987). The 12 percent gradient criterion is used by the Salmon and Steelhead Habitat Inventory and Assessment Project (SSHIAPP) to estimate the maximum potential extent of use by chinook, coho, sockeye, steelhead, and pink salmon; chum salmon are assumed to utilize only channels with a gradient of less than 8 percent. Although no known impassable barriers are mapped for the Upper Green River, the 12 percent gradient break generally coincides with the location of a series of cascades identified by Williams et al. (1975), supporting the presumption that this part of the channel probably represented the historic upstream-most extent of use by anadromous salmonids.

CULVERTS

There are no documented barrier culverts that would impede upstream migration in the mainstem Green River between Howard Hanson Reservoir and the confluence with Sunday Creek (Fox 1996; Fox and Watson 1997). However, a number of culverts that potentially prevent passage of juvenile salmonids into tributary streams have been identified (Figure Pass-1). Barriers to and in the tributary channels will be discussed in detail in Chapter 3.

HOWARD HANSON DAM

Howard Hanson Dam, located at RM 64.5, was constructed without upstream fish passage facilities. The Tacoma Headworks at RM 61.5 has blocked the upstream passage of anadromous salmonids in the mainstem Green River and to upriver tributaries since 1911. Upstream and downstream passage conditions at Tacoma's Headworks are described in the following section, (Middle Green River sub-watershed).

Construction of Howard Hanson Dam was completed in 1964. Flow is discharged from the reservoir through a 900-foot long, 19-foot wide concrete-lined horseshoe tunnel located near the south abutment of the dam. Two 10-foot by 12-foot high radial gates (invert elevation 1,035 feet) in the intake tower discharge flow through the tunnel in normal flow periods (Figure Pass-2). When water is stored behind the dam (spring and summer) flows are passed through a 48-inch bypass pipe that runs under the outlet tunnel and discharges into a stilling basin. The bypass entrance is an 8-foot square opening (elevation 1069 feet) with the 48-inch bypass pipe exiting through the floor of the bypass entrance. Flow through the bypass pipe (maximum discharge is 560 cfs) is controlled via a valve located on the downstream end (elevation 1,024 feet).

Plans are currently underway to improve fish passage at HHD. Downstream passage facilities will be provided as part of the USACE's proposed Additional Water Supply Project (AWSP). Tacoma will implement a fish trap and haul program as part of the Muckleshoot Indian Tribe/Tacoma Public Utilities Settlement Agreement. A fish collection facility will be constructed at the Tacoma Headworks, consisting of a fish ladder and holding facilities. Adult fish will be transported using a fish tank and truck. Any upstream passage of fish will be conducted under the direction of the NMFS and USFWS; upstream passage of fish currently listed as Threatened or Endangered under the ESA may be prohibited until it is demonstrated that the upstream passage program meets performance criteria (Hickey 2000a).

Upstream Migration

Howard Hanson Dam represents a complete barrier to the upstream passage of anadromous and resident fish. The Howard Hanson Dam Fish Passage Technical Committee (FPTC)[1] determined that a trap-and-haul facility in the vicinity of the Tacoma Headworks at RM 61 represented the most feasible method of passing fish over the 235- foot-high HHD. The FPTC does not consider construction of a fish ladder to pass anadromous salmonids over HHD a feasible alternative to restoring fish passage. If fish were passed into the 3.5-mile long reach upstream of the Tacoma Headworks, another barrier dam would have to be constructed between the Headworks and HHD to direct fish into the entrance of the HHD upstream passage facility. Howard Hanson Dam could not be used as a fish passage barrier because the outlet area is used to dissipate energy, thus fish would have a difficult time finding the entrance to a passage facility. The new barrier dam would have to be at least 12 feet high to ensure upstream migrants were successfully directed into the entrance of the passage facility, and would have to be located far enough downstream to avoid backwatering the HHD outlets.

Provision of upstream passage at HHD using a fish ladder with gradient of less than 12 percent would require a ladder at least 1,900 feet in length. Fish ladders of this length are uncommon because of habitat conditions within the ladder and water temperature concerns. Adult salmonids attempting to ascend a ladder of this length and height would be exposed to stress and potential

---

[1] The Fish Passage Technical Committee is an advisory group convened by Tacoma and the USACE. The committee is a broad-based group of public and private individuals experienced in the design and evaluation of fish passage facilities; members include independent consultants and specialists from WDFW and NMFS. The initial purpose of the FPTC was to provide a planning document for use in the development of a permanent downstream fish passage facility at HHD under the AWSP. The FPTC will continue to supervise, provide guidance, and recommend modifications of the facility during the final design and construction phases of the project.

water quality deterioration. According to draft Washington State guidelines, fish transit times through fish ladders should be less than about 6 hours, effectively limiting the maximum height of a fish ladder to about 90 feet (Bates 2000).

Another limitation to installing a fish ladder at HHD is the large fluctuation in the reservoir level. Since the primary function of HHD (as authorized by Congress) is flood control, the water level behind the dam can vary by more than 150 feet during times when adult salmon and steelhead are migrating upstream. During times when the pool elevation is low, the fish that ascended the 235-foot high ladder would then need to be lowered as much as 150 feet to the level of the reservoir pool behind the dam. This would require that the adult fish either be returned in a high-velocity slide/chute to the pool level or via some type of mechanical elevator. In either case, the fish would experience additional stress associated with the passage facilities.

In addition, since the HHD reservoir pool must be drained prior to the flood control season, returning fish to the reservoir near the dam could greatly increase the rate of adult fallback if the fish remained in the reservoir and the pool was drawn down rapidly to prepare for flood storage. As an alternative to returning fish to the downstream end of the reservoir, the fish ladder could be extended to the upper end of the pool; however, this would entail extending the fish ladder by approximately 7.0 miles upstream of the dam. While an upstream ladder of this length is theoretically feasible, the risk of failure is much higher than a trap-and-haul facility.

Downstream Migration

Since 1982, between two and four million juvenile salmon and steelhead annually have been released upstream of HHD (USACE 1998). Current annual survival of juvenile salmon and steelhead migrating through HHD outlets is estimated to be between 5 and 25 percent based on a fish passage model and on-site monitoring data (Dilley and Wunderlich 1992, 1993). There are two main concerns regarding donwstream fish passage associated with Howard Hanson Dam:

- **Passage through the dam**. The low survival rate of fish passing Howard Hanson Dam is primarily a function of two factors: 1) the spring refill operation strategy, which influences the ability of fish to locate the outlets;

- **Passage through the reservoir.** The low survival of juveniles passing through the bypass outlet pipe. The original operational strategy for the HHD project, generally followed from 1962 to 1983, delayed the start of reservoir refill until June and thereby would have provided successful passage of downstream migrants (if present) through the radial gates. Once reservoir refill was initiated, nearly all inflow was stored and only water required to satisfy the existing instream flow target of 110 cfs at Palmer was released. Storing the water as quickly as possible minimized the duration, but exacerbated the magnitude of downstream impacts by dramatically cutting flows to the lower river once reservoir refill began. The historic refill strategy reduced flows from an average of 1,140 cfs at Auburn to a low flow of 234 cfs for an average 12-day period in early June (USACE 1995).

Between 1984 and 1991, HHD reservoir refill was delayed to allow for outmigration of juvenile salmonids, primarily through the radial gates. Between 1992 and 1998, HHD reservoir refill commenced much earlier, beginning in late March to mid-April, and the bypass pipe was used more frequently. Changes in the refill operations since 1991 gave priority to downstream resources, in particular steelhead spawning and incubation. Instead of delaying refill until late May, refill was typically begun in early to mid-April, before the peak of outmigration from the Upper sub-watershed. This change in operations resulted in decreased survival of smolts in following years. In particular, during low runoff years, early refill and low outflow appear to entrap a large portion of the outmigrating juveniles (Dilley and Wunderlich 1992, 1993). In 1992, at least 42 percent of all coho smolts outmigrated after their normal emigration season, and an unknown number may have residualized or died before emigrating during fall drawdown (Dilley and Wunderlich 1993).

The primary conclusion of dam passage outmigrant studies conducted in HHD reservoir was that spring refill, especially early spring refill, substantially delays and/or entraps migratory juvenile salmonids (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992; 1993). Spring refill coincides with the main outmigration period of juvenile salmonids. As the pool fills, the outlets are submerged to depths of 35 to 112 feet. As inflow to the reservoir recedes, outflow from the dam is routed to the bypass pipe (flows less than 500 cfs).

During outmigration, juvenile fish may not find or be willing or able to use outlets that are deeply submerged. Juvenile fish require a near surface-outlet (typically 5 to 20 feet below the water surface) with a high discharge capacity outlet (exact volumes depend on site conditions). Therefore, at a time when fish need high flows and a shallow outlet, the project is reducing outflow (refill) and creating a deeper outlet (from 35 to 112 feet deep). Significant reductions in passage of coho yearlings during reservoir refill were observed in 1991. A large pulse of downstream yearling coho migrants was observed when discharge was switched to the radial gates in 1992, suggesting that fish are entrapped behind HHD when flows are passed through the bypass pipe during outmigration (Dilley and Wunderlich 1992; 1993). The USFWS researchers observed no significant relationships between passage of yearling chinook and outflow or operation of the bypass pipe. Chinook subyearlings were the only juvenile salmonids passing through the dam when the outlet pipe was submerged. However, the bulk of subyearling movement occurred during periods of high flows when the radial gates were in operation (Dilley and Wunderlich 1992; 1993). Of those smolts that do migrate downstream in the late summer and fall after being trapped in the reservoir, a large number are killed or injured because flows are generally passed through the bypass pipe at this time of year (USACE 1998).

Outmigrant studies indicate that there is little or no injury to juvenile fish using the radial gates (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992; 1993). Juvenile fish passing HHD through the 10-foot diameter radial gates drop 26 feet under 45 feet of hydraulic head into a stilling basin with a concrete floor. In 1984, using test and control releases of fish into the radial and bypass gates, WDFW observed little injury or mortality of captured steelhead and coho smolts that had passed through the radial gates (Seiler and Neuhauser 1985).

In contrast, fish that pass through the 48-inch bypass pipe experience high mortality from impacts at sharp bends or turns within the pipe. Direct mortality in the bypass pipe can range from 1 percent to 100 percent depending on the amount of flow, water temperature, pool elevation, and time of year. During passage studies conducted in 1984, smolts introduced into the bypass pipe were injured or killed at the following rates: of 347 coho smolts examined, 9 were dead or severely injured (2.6%); and of 29 steelhead smolts examined, 10 were dead (35%)

(Seiler and Neuhauser 1985). Researchers from the USFWS also found higher injury and mortality rates for juveniles captured after passing through the bypass pipe than those that passed through the radial gates. In 1992, over 33 percent of all chinook subyearlings and 14 percent of chinook yearlings captured were dead following passage through the pipe (Dilley and Wunderlich 1993). The same USFWS researchers considered the observed mortality rate to be much lower than the actual rate, as numerous dead and injured fish were sighted in the tailrace but never captured and counted. In addition, up to 36 percent of chinook subyearlings, and 37 percent of chinook yearlings were injured or fully- to partially-descaled. Higher head (higher pool elevation) and warmer water temperatures may increase the injury rate; during one three-day period in September 1992, almost 90 percent of all captured juvenile chinook that passed through the bypass were found dead (Dilley and Wunderlich 1992; 1993). Coho yearling mortality was also high; between 14 May and 25 September, 25 percent of the yearling coho captured were dead (Dilley and Wunderlich 1992; 1993). The mortality of coho subyearlings was the lowest of all life stages (5 %), but those fish had the highest rate of descaling (32%).

HYDROLOGIC BARRIERS

LOW INSTREAM FLOWS

Low flows in the Green River are most likely to adversely affect adult chinook salmon that begin moving upstream in August and September when flows are generally lowest. Adult chinook require flow depths of at least one foot for unimpeded upstream passage (Bell 1986). Recent high levels of coarse sediment inputs have transformed many sections of the river upstream of HHD from essentially a single-thread pool riffle channel morphology to a braided morphology consisting of numerous shallow flow paths (Cupp and Metzler 1996; O'Connor 1997). Consequently, the upstream passage of adult chinook salmon is susceptible to delays and/or blockage during water years marked by low flows during the late fall and winter. For example, recent observations by USACE personnel during August and September indicated that a section of channel located near RM 84 went subsurface at low flows (Goetz 2000). The Green River left its former channel at this site, cutting across an airstrip at the former Lester Airport; the newly carved channel is straight, steep and shallow with a braided morphology. Observations made in the same area near the end of August 1998 noted a series of impediments to the upstream migration of chinook (MITFD 1998). These impediments took the form of extensive areas of shallow flow (<2 inches deep) and sharp breaks in stream gradient. At gradient breaks, the stream rose 1 to 2 feet over a distance of 2-4 feet and no pools that would facilitate jumping had formed at the downstream end. This combination of shallow flows and steep gradient breaks would impair the upstream migration of adult chinook salmon, particularly at the end of a long, energetically expensive journey to reach the Upper sub-watershed.

In addition to low flow concerns in the mainstem Green River, low flows may impede passage of adult fish into some of the larger tributaries. For example, eleven tributaries evaluated for the Lester Watershed Analysis have formed relatively steep (4-10 percent) alluvial fans where they leave the mountains and flow onto the Green River floodplain (Cupp and Metzler 1996). Because of the porous nature of the sediment deposits that create such landforms, water flowing across the fans is rapidly lost to seepage, and flows may disappear before reaching the foot of the fan (Levin 1981). Recent increases in sediment delivery from road and timber harvest-related landslides, in conjunction with low levels of LWD are have exacerbated low flow concerns at a number of tributary junctions, including Olsen Creek, Sweeney Creek, Humphrey Creek, and a number of unnamed tributaries (Malcom 1998) (Figure Pass-1). Low flow concerns and other impediments to fish passage in tributary channels are discussed in detail later in the chapter.

Subsurface flows have also been observed in the North Fork Green River during late summer (Noble 1969; Hickey 2000b) and could prevent salmonids from entering the river or moving upstream. Tacoma operates a well-field that taps the North Fork Green River aquifer, using the water to partially replace surface flows when the turbidity of the Green River reaches 3 NTUs and to completely replace surface flows at turbidity levels of 5 NTUs or greater.

The risk that Tacoma's use of the well field would adversely affect fish is greatest in the late summer and early fall. Turbidity data collected from the Green River over a five year period in the 1960's indicated that it is unlikely that there would be a need to operate the well field during July and August. However, there have been flows with a turbidity in excess of 5 NTU's in September that would necessitate use of the well field (see Table HYDRO-1 in the Hydrology section of this report). If pumping were to occur without a concurrent storm-related rise in streamflow, adult salmonids holding in the lower North Fork Green River channel could be exposed to channel dewatering or prevented from moving upstream into the North Fork Green River. There currently are no data regarding the effect of well-field use on the up or downstream passage of salmonids in the North Fork Green River. However, it is believed that use of the wells can affect flows in the North Fork Green River. Groundwater dynamics and the North Fork well-field operation are discussed in detail in Chapter 2.1 (Hydrology).

HOWARD HANSON RESERVOIR

In addition to exit-related delay, entrapment and injury, there is concern that juvenile salmon and steelhead require additional travel time to migrate through Howard Hanson Reservoir. The size of a low velocity impoundment can affect the outmigration of juvenile salmonids by causing residualization, extending the duration of travel and decreasing fish survival. The size of HHD reservoir ranges from 100 acres (1.5 miles long) to 871 acres (approximately 4.6 miles long) depending on the pool elevation (Table Pass-1). During the winter flood control season, the reservoir behind HHD is essentially held empty (pool elevation below 1,070 MSL), except when floodwaters are retained to provide downstream flood protection, which are then subsequently released. Between floods, conditions in the HHD reservoir are run-of river. At the maximum summer conservation pool elevation of 1,141 feet MSL, which is generally achieved by early June, the surface area of the impoundment is 871 acres with a volume of 30,400 acre feet. The reservoir is approximately 4.6 miles long at this pool level and has a perimeter of about 13 miles.

Juvenile salmonids moving downstream during their spring outmigration must pass through Howard Hanson Reservoir before reaching the dam. When the reservoir pool elevation is held below 1,070 feet MSL, outmigrants are assumed to pass quickly and safely through the pool in conditions approximately equivalent to run-of-river. As the reservoir level rises, downstream migrating fish must pass through an increasingly larger slack-water area. Juvenile salmonids migrating though the larger reservoir pool can be delayed, which affects smolt survival, timing of ocean transition, and thermal imprinting. As a general rule, juvenile outmigrant fish appear to cue into changes in water velocity, and, except when holding for resting or feeding, move towards areas of higher velocities within the low velocity reservoir.

Aitkin et al. (1996) found that migration of juvenile coho salmon through Howard Hanson Reservoir took a significantly longer time at both mid- and high-pool elevations (Figure Pass-3). Travel times for both coho and steelhead smolts were longest at mid-pool. Travel time was more closely related to refill rate than pool level, increasing as refill rate increased (Aitkin et al. 1996). Chinook juveniles were released only at high pool and at that reservoir level had a travel time comparable to coho. All fish utilized in this study were from hatchery releases. Chinook juveniles released for this study were held for extended rearing with the objective of growing them to the size of coho smolt prior to release, but due to budgetary constraints and slower than expected growth the size of chinook released ranged from 107 to 117 mm. These lengths were somewhat smaller than the 130 mm threshold used for coho but larger than would be expected for naturally spawned sub-yearling chinook (Warner 1996). Aitkin et. al. (1996) also found a weak relationship between fish size and migration rate, suggesting that delay may be of most concern for small, young chinook. Unfortunately it is difficult radio tag fish this size.

Out of 234 fish released, 150 tags were ultimately recovered at the HHD forebay. The fate of the remaining fish is unknown. Receivers missed or created false detections for 25 percent of the fish; other fish were never detected by the fixed receivers (Warner 1996). Overall, only 35 percent of the chinook released were detected in the reservoir forebay (Warner 1996). The detection rate was somewhat greater for coho and steelhead (average rate of 54 percent and 69 percent respectively). However, the detection rate varied with pool level, generally increasing as pool level increased (Table Pass-2). Radio-tagging studies performed to date are a reasonable means of assessing travel time and delay, but they cannot be used to assess survival of fish through the reservoir. At this time, it is unknown whether the reason fish were not detected in the reservoir forebay was a result of equipment or tag failure, predation, or residualism. Although unpublished data indicate that a number of fish were lost to predation (Warner 2000), additional studies are required to assess the reason for the relatively low tag-detection rate.

BIOLOGICAL BARRIERS

WATER TEMPERATURE

The optimum temperature range for upstream migration of chinook salmon is between 49 and 57.5°F (Bell 1986). High temperatures increase the metabolic rate and result in the fish expending a greater amount of energy; adult fish have been known to cease migrating or die unspawned when subjected to extreme temperatures (Bell 1986). Lethal levels for adult salmonids vary according to such factors as acclimation temperature and the duration of the increase, but they are generally in the range of 73 to 84 °F (Bjornn and Reiser 1991; Caldwell 1994). Although the Upper Green River is not listed on the 1998 Washington State 303(d) list for temperature violations, water temperatures of inflow to HHD generally exceed the Class AA standard of 60.8°F at some point in most years (USACE 1998). This is greater than the preferred temperature range for rearing and spawning salmonids, and thus could delay upstream migration of adult fish. Furthermore, exposure to these temperatures occurs after the fish have undergone a stressful, energetically expensive journey through the warm waters of the Lower and Middle Green River and have ascended through the turbulent water and steep cascades of the Green River gorge. The effect of temperature-induced stress on the fitness and reproductive ability of salmonids in the mainstem Green River is currently unknown.

PREDATOR CONCENTRATIONS

There is currently no data on the rate of predation on downstream migrating juvenile salmonids in the HHD reservoir. Past experience at other Pacific Northwest reservoirs has revealed that downstream migrating juvenile salmonids may encounter increased predation when they enter a low velocity impoundment. Populations of predators (e.g., northern pike minnow [Ptychocheilus oregonensis]) have been listed as a cause of lower survival of juvenile salmonids in many Pacific Northwest systems (Cada et al. 1994; Ledgerwood et al. 1994). Rieman et al. (1991) estimated that 14 percent of all juvenile salmonids that enter the John Day Reservoir on the Columbia River are consumed by a combination of northern pikeminnow, walleye (Stizostedion vitreum), and/or smallmouth bass (Micropterus dolomieui). Surveys of the HHD Reservoir to date have not identified warmwater gamefish or northern pikeminnow; however, large resident trout or residualized salmon represent a predation risk to downstream migrating salmonids (Tacoma 1999).

MIDDLE GREEN RIVER SUB-WATERSHED (RM 32 TO RM 64.5)

PHYSICAL BARRIERS

NATURAL BARRIERS AND IMPEDIMENTS

There are no natural physical barriers or impediments to upstream migration on the mainstem Green River in the Middle Green River sub-watershed.

SOOS CREEK WEIR

From 1904 to 1924, a wooden weir was erected annually near the on the mainstem Green River at the confluence of Soos Creek to allow capture of adult chinook in the mainstem (Becker 1967). The weir often washed out during high flows in October, however, presumably allowing numerous fish to escape and continue upstream.

TACOMA HEADWORKS

In 1913, construction of Tacoma's Headworks Diversion Dam at RM 61.0 was completed 3.5 river miles downstream of the eventual site of HHD (Figure Pass-4). The existing concrete gravity diversion dam is 17 feet high with a crest length of 150 feet. The dam is founded on bedrock and both abutments are keyed into rock. The diversion supplies water to a pipeline that carries water from the diversion dam south and west to Tacoma. The pipeline has a capacity of 113 cfs. The existing intake is 20 feet wide and located in the right abutment immediately upstream of the existing diversion dam.

The existing Headworks dam currently lacks permanent upstream and downstream fish passage facilities and represents a complete barrier to upstream migrating adult salmonids. Plans are currently underway to modify the Headworks as part of the Second Supply Project and include provisions for both upstream and downstream passage facilities.

Upstream Passage

The Tacoma Headworks diversion dam was the first complete barrier to adult salmon and steelhead in the Green River. It eliminated naturally reproducing anadromous fish production in the Upper sub-watershed for 80 years. Since 1992, the Muckleshoot Indian Tribe (MIT), Tacoma, WDFW, and Trout Unlimited have cooperatively administered a temporary fish ladder and trap-and-haul program. Under the pilot program, between 7 and 133 adult steelhead have been captured at the Headworks fish trap and either released upstream of HHD for natural spawning or used to produce fry for outplanting in the Upper Green River sub-watershed.

Downstream Passage

The existing Headworks has minimal fish screening facilities. Two routes are currently available to juvenile fish migrating downstream below Tacoma's existing Headworks. The first is direct passage over the dam spillway. Water flows over the dam and onto a flat concrete apron (Figure Pass-5)

In general, mortality of juvenile fish passing over dams is a function of the height of the structure, the maximum velocity of water (which is primarily dependent on dam height), and the configuration of the channel immediately downstream of the dam. For small fish (<100 mm), mortality is near zero even for falls of as much as over 100 feet, provided they land in water (Figure Pass-6). Larger fish (>300 mm) begin to experience mortality at falls greater than 50 feet (Figure Pass-6). Fish mortality is also influenced by the maximum velocity of the flow passing over a dam (Figure Pass-7). Where flows passing over a dam empty into a deep pool or stilling basin, mortality is essentially zero at velocities less than 40 feet per second (fps). However, shallow flow or obstructions such as exposed rocks below the spillway appear to increase the rate of mortality (Figure Pass-7) and injury. Approximately seven to eight percent of the juvenile salmonids passing a 190-foot high sediment retention structure on the North Fork Toutle River were injured by passage down a 480-foot long section of an exit ramp with a rough surface that discharged into a pool containing large rocks at a velocity of 50 fps (Seiler et al. 1992).

Although there is no site-specific information on the hydraulic conditions or injury or mortality of fish at the Tacoma Headworks diversion dam, information from studies at other projects suggest that the rate of mortality experienced by juvenile fish passing over a 17-foot spillway is probably low (R2 1998; Seiler et al. 1992). Fish passing through the radial gates at HHD drop 26 feet onto a concrete slab with no apparent injury (Seiler and Neuhauser 1985). However, because the channel configuration downstream of the Headworks diversion dam consists of a shallow concrete apron (Figure Pass-8), it must be assumed that juvenile and adult salmonids passing downstream over the Tacoma Headworks under its current configuration could be injured at some flows.

The second avenue of passage available at the Headworks is the pipeline intake. The existing intake screens are galvanized steel measuring 1/4" from center strand to center strand, with 5/32" openings. The existing Headworks intake screens do not meet NMFS or State screen criteria and juvenile salmonids can potentially be impinged on the intake and killed (Tacoma 1999). In addition, very small juvenile salmonids could pass through the existing screens.

Under its First Diversion Water Right Claim (FDWRC), Tacoma has withdrawn up to 113 cfs of water at the Headworks diversion facility since 1913. Before about 1950, withdrawals were generally less than 113 cfs. However, since about 1950, the pipeline has been operated at capacity. During periods of high turbidity, the North Fork well field is used as an alternate source of clear water or mixed with surface water from the Green River to reduce turbidity levels to less than 5 NTU's. Since periodic high turbidity events are relatively common during the spring, the actual average daily withdrawal during the period juvenile salmon are migrating downstream (February through June) is currently somewhat lower than 113 cfs. For 1997 through 1999, average daily withdrawal from the Green River was 89.3 cfs for March, 88.3 cfs for April, 93.3 cfs for May, and 106.7 cfs for June (Hickey 2000c). These withdrawals represent approximately four to nine percent of the average daily flows (Table Pass-3).

In addition, fish congregating in front of the screens were often drawn into the intake when the screens were being cleaned (Hickey 2000a). Juvenile salmon believed to have been released upstream of HHD have been identified in McMillin Reservoir (Finney 2000). Fish entrained into the flow line no longer contribute to the Green River salmonid population.

In 1997, backup screens were installed behind the regular screens in order to maintain a screened intake when the front screens were being cleaned (Figure Pass-8). Since that time, no juvenile salmonids have been observed in McMillin reservoir (Hickey 2000b). The physical and flow characteristics of the backup screens are similar to the primary screens. Consequently, the potential for injury and mortality when the backup screens are in use is the same as that for the primary screens.

CULVERTS

There are no stream crossings (culverts or bridges) that represent barriers to upstream or downstream passage in the mainstem through the Middle Green River sub-watershed. A number of culverts and levees that prevent access to tributary channels and off channel have been identified (Figure Pass-4). These barriers may prevent access to protected lateral habitats for juvenile salmonids rearing in the mainstem Green River. Passage barriers on individual tributaries will be discussed in further detail later in this chapter.

HYDROLOGIC BARRIERS

LOW INSTREAM FLOWS

Between RM 32 and RM 45, the Green River is unconstrained by levees in many areas and is therefore substantially wider than the channelized Lower Green River (RM 0 to RM 25) or the Green River gorge (RM 45 to RM 58). The current morphology of the Middle Green River was largely determined by major floods in the late 1950s, before construction of HHD (Perkins 1993). Thus, under the existing flow regime, the Green River channel from RM 32 to RM 45 is wider and shallower than would be expected in a similar river with a similar natural flow regime. At a flow of 1,000 cfs at Auburn, the average wetted width of the middle Green River was 148 feet as compared to 119 feet in the lower Green River (Caldwell and Hirschey 1989). Historically, the wetted width has been substantially narrower than 148 feet when chinook began spawning in early September through October because flows at that time rarely exceeded 600 cfs and were often less than 400 cfs (Malcom 2000).

Under the existing flow regime there are a number of areas where the upstream passage of chinook is susceptible to blockage or impairment during low flow conditions (Figure Pass-4). Analysis of transect and stage:discharge data collected at shallow riffles in the Middle Green indicated that flows of 225 cfs had a depth of at least one foot (Caldwell and Hirschey 1989), which should provide sufficient upstream passage for adult chinook salmon. However, surveys conducted by the Muckleshoot Indian Tribe between 30 August and 1 September 1999, found an average depth of 0.74 feet over riffles. In many instances, the average depth over individual riffles was shallower and no deeper water routes around the riffle were observed (Malcom 2000). Flows at Auburn during those surveys ranged from 291 to 301 cfs (USGS 2000). Historically, late summer low flows lower than 225 cfs were common and have been known to impede the upstream migration of adult chinook salmon. For example, during severe drought conditions in 1987 when annual seven-day low flow at the Auburn gage was 157 cfs, the MIT and WDFW hand-excavated channels through riffles in the vicinity of Neely Bridge (RM 41) to provide adult salmon passage through shallow areas (Hickey 1999).

The extent to which the recently observed low flow barriers exceed those that would have occurred under natural conditions is unclear. The extent of braided and multiple thread channels was greater in the early part of the 20th century, which may have resulted in flows low enough to restrict passage to upstream reaches even under natural conditions. Such barriers may serve to prevent fish from entering areas where they would otherwise be susceptible to high water temperatures or predation. However, changes in the flow regime, sediment transport regime, and physical habitat have likely exacerbated natural low flow conditions and are believed to have negatively impacted anadromous salmonids in the Green River (Grette and Salo 1986).

BIOLOGICAL BARRIERS

WATER TEMPERATURE

Several sections of the Middle Green River are currently on the 1998 303(d) list because of water temperature concerns (Figure Pass-4). The 303(d) list identifies stream segments where "beneficial uses", including fish habitat, are impaired. NMFS indicates that water temperatures between 50 and 57 ^{o}F are considered to be functioning properly for salmonid migration and rearing; temperatures greater than 57^{o}F are functioning "at risk," and temperatures greater than 64 ^{o}F are considered to be "not properly functioning" (NMFS 1999).

Upstream of Flaming Geyser Park (RM 42.9), the Green River is classified as a Class "AA" water and must meet the State water temperature criteria of 60^{o}F. In the early summer, water temperatures of the HHD outflow are generally lower than the inflow temperatures, as water is drawn from the lower reservoir levels. By late summer the supply of cool water is exhausted and water temperatures increase somewhat (USACE 1998). In 1992, maximum equilibrium[2] temperatures of the HHD outflow generally ranged from 60 to 64 ^{o}F in August before showing a cooling trend in September from 63^{o}F early in the month to 52 ^{o}F late in the month (Caldwell 1994). Temperatures below HHD in August and early September are therefore functioning "at risk" for migration and rearing according to the NMFS criteria (Table Pass-4).

---

[2] Maximum equilibrium temperatures was defined as the maximum water temperature present on at least 5 to 10 occasions within the month (Caldwell 1994).

Water temperatures at the Tacoma Headworks are generally independent of the HHD outflow temperature, suggesting the influence of cooler outflows from HHD extend only a limited distance downstream of the dam (Caldwell 1994). Maximum equilibrium temperatures throughout July and August at the Tacoma Headworks exceeded 64 ^{o}F (Caldwell 1994). While these water temperatures exceed the range considered optimal for upstream migration and could result in avoidance, delays, stress, disease and increased pre-spawn mortality, they are below lethal limits (Table Pass-4).

No water temperature data are available within the Green River gorge but water temperatures there are hypothesized to be cooler. Direct solar radiation occurs over a limited time period because the gorge is shaded by high and steep sideslopes. In addition, groundwater inflows associated with springs mapped on USGS topographic maps are believed to contribute cooler water. For these reasons, the gorge might be expected to provide holding habitat for adult salmonids during the late summer when temperatures elsewhere in the river are high.

Between RM 42.3 and RM 31, the Green River is classified as a Class "A" water and must meet a water temperature standard of less than 64 ^{o}F (WDOE 1998). Multiple excursions beyond the standard were recorded at RM 41.5 and RM 35 in 1992. Maximum equilibrium temperatures in August ranged from 72.5 to 75.2 ^{o}F (Caldwell 1994), which was within the range of potentially lethal temperatures (Bjornn and Reiser 1991). Moreover, water temperatures exceeded 64^{o}F for 30 to 40 percent of the total hours measured in August (Table Pass-5).

Water temperature in rivers in the Pacific Northwest often is a function of elevation and shading (Sullivan et al. 1989). While the Green River is too wide for even mature riparian vegetation to completely shade the entire channel in many reaches, particularly braided sections, surface water temperature differences were measured between reaches of similar elevation and different riparian character (Caldwell 1994). Actual high water temperatures were similar, but the extent and duration of high temperatures was lower in reaches with intact riparian zones or trees on top of hydromodified banks (Caldwell 1994).

Pools may serve as thermal refuge areas for rearing juveniles and upstream migrating adult fish during the summer months in areas where they are fed by seeps of groundwater inflow or intragravel flow (Bilby 1984; Nielsen et al. 1994). Pool temperatures in August 1992 were investigated to determine whether such refuge areas were present in the Middle Green River (Caldwell 1994). In all 27 pools surveyed over a 7.5 mile reach between RM 34 and 41.5, water temperatures were the same as water temperatures in non-pool habitat (62 to 64 ^{o}F), suggesting a complete mixing of the water column and that thermal refugia are generally not available to upstream migrating adult salmonids in the Middle Green River (Caldwell 1994). Surveys of pools between RM 33 and RM 42 conducted by the MIT in August 1998 also found no difference between surface water temperatures and pool bottom temperatures (Malcom 2000).

BEHAVIORAL BARRIERS

During the months of July, August, and parts of September, the Green River between Flaming Geyser Park and Soos Creek is used extensively for recreational boating. Streamside recreation or fish viewing activities have been observed to reduce the rate of upstream coho migration (Malcom 1996). In-water activities such as canoeing also have been observed to displace adult coho salmon downstream (Malcom 1996). Because of the smaller channel and higher level of boating activity during the period when adult chinook salmon migrate upstream, a similar displacement would be expected to occur with adult chinook. The potential for instream recreation to impair the upstream migration of adult chinook salmon is emphasized by the response of chinook on redds to recreational boating. In 1993, the Sawtooth National Forest (SNF) reported that displacement of salmon from redds had been observed in association with floatboating activities (SNF 1994a,b,c,d). Displacement of salmon from redds disrupts spawning activities. Since salmon travel long distances to reach spawning areas, they have limited energy reserves for spawning. Displacement of salmon from redds may result in incomplete redd construction, selection of less preferred redd sites, and incomplete spawning. These occurrences could reduce the number of fry emerging from the gravel the following spring (SNF 1994a,b,c,d). Incomplete spawning includes eggs not released from the female, egg scattering, inadequate coverage of the eggs, and eggs released at redd depths insufficient to foster proper incubation (SNF 1994a,b,c,d).

In addition to direct disturbances, mammalian odors, such as those arising from dogs and people, have been observed to temporarily disrupt and slow the upstream migration rate of adult coho and chinook salmon, although the rate of upstream migration recovered within thirty minutes (Brett and MacKinnon 1954). Observations in the Sammamish River, where mammalian odors were accompanied by instream activities such as boating or swimming dogs, suggest that instream activity can displace hundreds of salmon downstream and that the recovery time can exceed two hours (Malcom 1996). Salmon will expend energy as they are displaced downstream and then must again expend energy to move back upstream. In portions of the river with elevated temperatures, the energy loss and stress has the potential to increase pre-spawn mortality and decrease reproductive success. This problem is particularly important in the Middle Green River due to the exposure of upstream migrating adult chinook to elevated water temperatures

LOWER GREEN RIVER SUB-WATERSHED (RM 11 TO RM 32)

PHYSICAL BARRIERS

NATURAL BARRIERS AND IMPEDIMENTS

There are no natural impediments to upstream or downstream migration of anadromous salmonids in the lower mainstem Green River.

BLACK RIVER PUMPING STATION

In 1958, an earthen dam was constructed on the Black River approximately 1,000 feet upstream of the confluence with the Green River. The purpose of this structure was to control outflows from the Black River and to prevent flows on the Green River from backing up into the Black River/Springbrook Creek floodplain during floods. Six 48-inch diameter culverts extended through the dam and were fitted with flapgates. In 1972, the U.S. Soil Conservation Service (SCS) replaced the dam with the Black River Pumping Station (BRPS) to provide a means of releasing flood flows from the Black River/Springbrook Creek system when the Green River is at high stage. The BRPS is currently operated and maintained by King County Department of Natural Resources. Except where indicated by specific citations, the following description of the

BRPS and associated fish passage facility comes from a comprehensive fisheries assessment of the Mill, Garrison and Springbrook Creek system conducted for the Cities of Kent and Tukwila (Harza 1995).

During flood periods on the Green River, the pumping station acts as a dam, preventing floods from backwatering into the Black River and the wide valley floor of the lower Springbrook Creek system. Water levels downstream of the pumping station range from –4.0 to +21.5 feet MSL, depending on tidal conditions and the water level of the Green River. Water surface elevations upstream of the pumping station are normally held in the range of 0.0 to 2.0 feet, but can reach as high as 13.0 feet. The pumping station consists of a series of eight pumps, and can pass flows of up to 2,945 cfs. Two large pumps with a capacity of approximately 1,028 cfs are also present, but have not yet been brought on line.

The BRPS represents a barrier to the upstream passage of salmonids. In addition, the ability to control the water surface elevations upstream of the BRPS often results in a situation where the downstream water surface is higher than the upstream water surface. In order to pass upstream and downstream migrating salmonids around the structure, a unique fish passage system has been constructed and is in operation. A combination of a fish ladder and fishway chute are used for upstream passage. Fish migrating downstream are diverted around the pumps using an air lift pump to raise the fish to the downstream water levels. The general layout of the BRPS and fish passage facilities are illustrated by Figure Pass-9

Upstream Passage

Upstream fish passage facilities are located on the south side (left bank) of the pumping station. They consist of a combination fish ladder and fishway chute (Figure Pass-10). The main components of the upstream fish passage facility are a supply pump, denil fish ladder, a false attraction weir, and a fishway chute. Fish enter the denil fishladder, swim up and over the false weir, and are then returned to the river upstream of the project via the fishway chute.

The denil ladder extends from the downstream pool on the south side of the BRPS approximately 60 feet horizontally and 14 feet vertically to a resting pool below the false weir. From the resting pool, fish enter the second portion of the ladder that extends 25 feet horizontally and seven feet vertically to the top resting pool. The velocity of the five cfs flow directed through the ladder is approximately 2.5 to 3.0 feet per second. This velocity is well within the normal range for this type of ladder and is suitable for adult salmon (Bell 1986). These velocities are at the upper limit of sustained swimming speeds for juvenile fish (Bell 1986) and thus likely prevent upstream migration of juvenile fish.

From the top resting pool, fish pass over the false weir and down the fishway chute. The fishway chute drops from approximate elevation 16.0 feet to 2.0 feet, creating a potential vertical drop of 2.0 feet at the end of the chute when the upstream water surface is held at 0.0. The 60 foot long chute is an open channel for the first 10 feet, a closed pipe for 25 feet and ends in an open channel for the final 25 feet. The inside of the chute is coated with vinyl to protect fish from abrasion.

The upstream passage facility is normally operated from mid-September through 31 January of each year. Before 1993, the upstream passage facility was usually operated 24 hours per day, Monday through Friday. Since 1993, the upstream passage facility has been operated about 24 hours per day, seven days per week, during the seasonal window. The operational seasonal window likely precludes the upstream migration of some anadromous and resident cutthroat trout and steelhead.

The species composition of fish migrating upstream was assessed in 1994 by trapping adult fish in a net pen installed in the forebay of the BRPS, immediately below the outflow of the fishway chute (Harza 1995). A total of 229 coho salmon and 14 chinook were trapped between 17 September and 9 December (Harza 1995). Fair coho spawning habitat was noted in some reaches, although the streambed appeared to be unstable and flow levels may have been insufficient for successful spawning (Harza 1995). Stream temperature and dissolved oxygen levels often reached lethal levels during the time when adult chinook were present (Harza 1995). Springbrook Creek is on the 1998 303(d) list for exceeding temperature and DO criteria at RM 0.1 and 1.5 (WDOE 1998). Adult salmonids, including chinook, that move upstream past the BRPS cannot exit the Springbrook system as there are no provisions in the downstream passage facility to allow them to do so. Once adult salmonids are allowed upstream they are believed to experience high levels of stress or be killed outright prior to successful spawning (Harza 1995).

Downstream Passage

The downstream passage facilities provide a means of transporting juvenile salmonids migrating towards the ocean around the BRPS. The downstream fish passage facility consists of entrance fish ports and associated piping, an air lift system, deaeration tank and transport pipe (Figure Pass-13). Fish travelling through the system enter through the fish ports on the upstream side of the dam. The fish are then transported to the air lift system and into the deaeration tank. Fish exit the deaeration tank via a bypass pipe that delivers them to the pool downstream of the dam.

The entrance ports to the system are located at elevation +2.0 and –2.0 and are adjacent to the fish screens for the pumps on the south half of the structure on the south side of the BRPS (Figure Pass-13). The airlift pumps draw flow into the transport pipes, attracting fish to the entrance ports. Fish travelling downstream move across the screens and into the ports. Except for the two large pumps, fish are prevented from entering the pumps by 1/4 inch mesh screens. To date the large, unscreened pumps have not been used during the late winter or spring (April to June). The existing screens and their placement do not meet current NMFS screening criteria.

After entering the fish ports, the fish descend a vertical fiberglass pipe to elevation –17.0 feet, and are then directed towards the airlift through a horizontal collection pipe. As the horizontal pipe passes into the airlift chamber, it turns vertically 90 degrees and descends to elevation –39.0 feet. At this point, the fish go through two more 90 degree elbow turns and then enter the airlift pump. Air added at –39.0 feet displaces water at the base of the vertical column, lifting the fish to +13.0 feet and into the deaeration tank.

The dimensions of the five-foot deep deaeration tank are 9.5 feet by 9.5 feet. The entrance to the 18-inch diameter fiberglass downstream transport pipe is located at the west end of the tank. This pipe transports fish approximately 108 feet horizontally to the fishway exit. The exit invert pipe is at 10.0 feet elevation, which can vary in height above the receiving water; normally, the drop is approximately 6 feet from the pipe to the receiving pool.

The downstream passage facility is operated from early-April to mid-June each year, for approximately eight hours per day, Monday through Friday. Fish attempting to move downstream outside of that operational window are either prevented from exiting the Springbrook system or must pass through the unscreened large pumps (if operational). Juvenile chinook emerge and begin moving downstream in the Middle Green River system and Soos Creek as early as February (Jeanes and Hilgert 2000). Consequently, early downstream migrants may be prevented from exiting the Springbrook system. Adult salmonids cannot pass downstream via the downstream fish passage facility.

Flapgates

Flapgates have been installed on many of the tributaries to the Lower Green River to control backwatering that may occur during floods. The flapgates allow discharge from the tributaries to the Green River during low flow periods, but are forced shut by water pressure when the flow level of the Green River exceeds the elevation of the outlet, thereby preventing water from the Green River from flowing into the tributaries. The design of these flapgates also prevents juvenile salmonids overwintering in the lower river from accessing lower velocity off-channel habitats during flood flows. Individual flapgates on smaller tributary streams are discussed in more detail in Chapter 3.

HYDROLOGIC BARRIERS

LOW INSTREAM FLOWS

No areas of low instream flows that could act as a barrier to upstream migration of adult salmonids have been identified in the lower Green River. The river is typically confined between levees throughout this reach, and thus has a lower width to depth ratio than might be expected under natural conditions.

BIOLOGICAL BARRIERS

WATER TEMPERATURE

Between RM 11 and RM 31, the Green River is a Class A waterbody. Numerous violations of the Class A temperature criteria (64 ^{o}F) have been recorded at RMs 12.5, 14.0, 18.3, 20.0, and 27.0 (Table Pass-4). In 1984, Fisheries Sciences reported maximum water temperatures of 73 to 74 ^{o}F near RM 11 (Fisheries Sciences 1984 as cited in Caldwell 1994). Since 1984, the METRO (King County) Renton Water Treatment Plant outflow has been routed out of the Green River and into Puget Sound, changing conditions near RM 11. However, Caldwell (1994) also measured maximum equilibrium temperatures ranging from 72 to 74 ^{o}F in this reach and found that temperatures exceeded 64 ^{o}F up to 71 percent of the time during August. These temperatures exceed the range required for properly functioning habitat according to NMFS (1999) and sometimes reach potentially lethal levels (Table Pass-4).

A number of investigators have indicated that high water temperatures may delay adult upstream migration in the Lower Green River sub-watershed (Figure Pass-12). Grette and Salo (1986) stated that elevated river water temperatures in this section of the river delayed the upstream migration of chinook. However, no specific information regarding the frequency, duration, or effect of temperature-related delays on the upstream migration of salmonids was located.

BEHAVIORAL BARRIERS

Behavioral barriers in the Lower Green River are generally similar to those described earlier for the Middle Green River, although disturbance is believed to be less. This is because this section of the river is not used as extensively for in-stream recreation, although there is an expanding trail system on top of the levees.

GREEN/DUWAMISH ESTUARY (RM 0 TO RM 11)

PHYSICAL BARRIERS

The mainstem Duwamish River and Estuary is largely a deepwater channel with no physical barriers to upstream or downstream migrations by adult or juvenile salmonids (Figure Pass-12).

A number of small tributaries to the Duwamish Estuary that may have supported rearing by juvenile chinook salmon in the past have been isolated from the estuary by diking and filling with placement of culverts, often with tide gates, through the fill. The mouth of Hamm Creek has been partially restored in recent years to the point where juvenile chinook salmon can access habitat in the lower reaches of the creek that has been inaccessible for decades and adult coho are accessing the stream for spawning. In the channel behind Kellogg Island, the Port of Seattle excavated a channel into a small, 0.4-acre, off-channel wetland (the Puget Estuary) at Terminal 107. The site has been planted with wetland plants and the surrounding slopes with upland buffer plants. The Port of Seattle is evaluating the potential for daylighting Puget Creek into this estuary to further improve habitat for anadromous fish. Until that happens, Puget Creek remains inaccessible to salmonids.

HYDROLOGIC BARRIERS

The mainstem Duwamish River and Estuary is largely a deepwater channel with no hydrologic barriers to upstream or downstream migrations by adult or juvenile salmonids.

BIOLOGICAL BARRIERS

Historically, late summer water quality conditions (low dissolved oxygen and high temperature) in the estuary likely constituted a temporary barrier to upstream migration by adult chinook salmon [Salo 1969; see Chapter 1.2, (Water Quality)]. As late as 1985, kills of adult chinook were reported (LeVander 1999). However, since the diversion to Puget Sound of the outfall from the Renton sewage treatment plant in 1986, these conditions have not been recently reported.

Although chemical and thermal barriers do not appear to be present currently in the Duwamish Estuary, a gradual upward trend of maximum summer temperatures in the estuary has been shown, with temperatures reaching 23°C (73.4°F) in surface waters between RM 3 and 7 in 1995. These temperatures, if present throughout the water column (which is unlikely), could have delayed upstream movements of adult salmon (e.g., Bell 1986). This trend, if continued, could result in a return to conditions of the 1970s and 1980s when water quality barriers occurred with regularity.

MAJOR TRIBUTARIES

PHYSICAL BARRIERS

SOOS CREEK (RM 0 – RM 13)

Natural Barriers and Impediments

The headwaters of Soos Creek arise on a rolling glacial outwash plain. In such landforms, streams often originate in wetlands and exhibit low gradient palustrine type channels (Chapter 2.3) until flows become sufficient to regularly transport coarse sediment. The gradient of mainstem Soos Creek is 1 to 2 percent throughout its course (Cutler 2000) and no natural barrier falls or cascades have been identified (Williams et al.1975). The upstream extent of spawning by anadromous fish, including chinook salmon, is not known, but is presumed to be limited by flow, substrate, or in-stream vegetation and not gradient. Juvenile fish are expected to use the entire length of available channel and associated wetlands for rearing.

Soos Creek Hatchery and Weir

The Soos Creek salmon hatchery, located at RM 0.7, was constructed in 1901 and has been in continuous operation since that time. Between 1902 and 1924, portable double racks were installed in the mainstem Green River at the mouth of Soos Creek to provide eggs for the hatchery, since chinook salmon did not enter Soos Creek at that time (Becker 1967). Annual installation of the portable weirs on the mainstem was discontinued in 1924, as large numbers of chinook had begun to return to Soos Creek by that time (Becker 1967).

The existing hatchery rack consists of two removable weirs located approximately 100 feet apart that are used to create a holding pond (Figure Pass-14). The weirs are generally installed around August 15, when the first chinook begin to arrive and removed around the third week of November when coho egg take requirements have been met (Chamblin 2000). A sheet-pile dam, used to divert water into the hatchery, is located just upstream. The diversion dam is equipped with a fish ladder (Figure Pass-15).

The hatchery rack acts as a barrier when it is in place. However, large storm events or other unforeseen occurrences may wash out the weirs or allow fish to pass the structure. For example, during a storm in September 1997, over 8,000 chinook were able to leave the hatchery and move upstream into Soos Creek when the weir failed (Finney 2000). Beavers have also been responsible for causing holes that allow adult salmonids to migrate upstream (Kerwin 2000). When the hatchery weirs are not in place, anadromous salmonids can move freely upstream. The hatchery does not interfere with the downstream movement of juvenile fish.

Culverts

Although a number of barriers associated with road crossings have been identified on tributary streams (Figure Pass-4), no existing barriers to upstream migration in mainstem Soos Creek have been identified. However, there are numerous barriers on tributary streams, which are discussed in Chapter 3. No systematic survey of barriers has been completed in the Soos Creek drainage but it is expected that additional barriers, including possible barriers on the mainstem, may be located in the future.

NEWAUKUM CREEK (RM 0-RM 12)

Natural Barriers and Impediments

There is no observational data of the upstream-most extent of use by anadromous fish in Newaukum Creek. However, chinook have been observed as far upstream as RM 12.0 (Spawning Ground Survey Database, WDFW). The presumed upstream extent of use by chinook, steelhead, and coho, estimated by identifying the location at which the channel gradient steepened to over 12 percent, occurs at approximately RM 13.5 (Cutler 2000). The 12 percent gradient break identified on Newaukum Creek occurs about ½ mile downstream of an impassable cascade near RM 9 identified by Williams et al. (1975).

Culverts

No barriers associated with road crossings have been identified on mainstem Newaukum Creek. However, since no systematic survey of barriers has been completed in the Newaukum Creek drainage, it is expected that barriers could be located in the future.

HYDROLOGIC BARRIERS

SOOS CREEK

Low Instream Flows

Low flows reportedly reduce the ability of chinook to reach the Soos Creek hatchery (WDFW and WWTT 1994). This influences natural spawning downstream of the hatchery as well as the number of chinook that may be released upstream of the hatchery rack. The specific location of low flow concerns was not identified and could include low flow concerns in the mainstem (WDFW and WWTT 1994). However, a declining trend in the average 7-day low flows just upstream of the hatchery has been identified (Culhane 1995) and is discussed in more detail in Chapter 2.1 (Hydrology). Declining flows support the hypothesized low flow concerns in Soos Creek.

NEWAUKUM CREEK

Low Instream Flows

Deposition of gravel at the mouth of Newuakum Creek where it enters the Green River floodplain has created a small alluvial fan. Because alluvial fans are formed of deep, porous deposits of generally coarse sediment that readily transmits water, streams flowing across such sites are naturally highly vulnerable to low or subsurface flows (Levin 1981). Shallow or subsurface flows currently impede the upstream migration of adult chinook salmon into Newuakum Creek, especially the early run component (Malcom 1999; Boehm 1999). Passage impediments are further exacerbated by the lack of deep holding pools on the fan and throughout the lower mile of channel in Newuakum Creek (Malcom 1999).

No information describing the specific location of low flow concerns was located for the remainder of Newaukum Creek. However, as with Soos Creek, a declining trend in the average 7-day low flow has been identified (Culhane 1995). The average 7-day low flow generally occurs during the period when chinook salmon are migrating upstream, suggesting that additional areas of low flow concerns may be present in Newaukum Creek.

BIOLOGICAL BARRIERS

SOOS CREEK

Water Temperature

There are no segments of mainstem Soos Creek listed on the 1998 Washington State 303(d) list for temperature concerns (WDOE 1998). Consequently, temperature is currently assumed not to limit the upstream migration of adult salmonids in Soos Creek. However, temperature concerns that represent potential passage barriers have been identified on a number of tributaries (Figure Pass-4). In addition, dissolved oxygen levels less than 8 mg/l have been recorded near RM 10. Low DO levels could cause salmonids to avoid entering this section of the stream, thereby delaying upstream migration.

NEWAUKUM CREEK

Water Temperature

There are currently no segments of mainstem Newuakum Creek listed on the 1998 Washington State 303(d) list due to temperature or DO concerns (WDOE 1998). However, temperatures greater than the NMFS criteria for properly functioning habitat (57^{o}F) have been recorded at the USGS gage near RM 1.0 (Malcom 1999).

LIST OF TABLES

Table Pass-1. Howard Hanson Reservoir Pool Physical characteristics at various pool elevations (USACE 1998).

Table Pass-2. Tag detection success rate at the forebay for salmoninds released into Howard Hanson Reservoir in 1995 (Warner 1996).

Table Pass-3. Average withdrawal at TPU Headworks as a percentage of mean daily flow during the period when juvenile salmonids are migrating downstream (Source: TPU 2000).

Table Pass-4. Recorded temperature conditions relative to water quality standards, NMFS habitat criteria for migration and rearing and potential lethal limits at various locations within the mainstem Green River.

Table Pass-5. Results of temperature monitoring conducted on the mainstem Green River in 1992 (from Caldwell 1994).

LIST OF FIGURES

Figure Pass-1. Known anthropogenic barriers in the upper Green River sub-watershed.

Figure Pass-2. Cross-section of Howard Hanson Dam (Source: USACE 1998).

Figure Pass-3. Mean travel times of coho, chinook and steelhead smolts through three pool conditions (Source: USACE 1998).

Figure Pass-4. Known anthropogenic barriers in the middle Green River sub-watershed.

Figure Pass-5. Tacoma Headworks Diversion dam, RM 61 (Source: Tacoma Public Utilities)

Figure Pass-6. Relationship between freefall height and mortality of salmonid fish. Mortality curve is near zero for fish less than 10 cm in length. Mortality estimates obtained from: (a) aerial drop of coho salmon and rainbow trout from helicopter (Regenthal 1956); and (b) aerial drop of atlantic salmon from tower (Sweeney and Ritchie 1981). (Source: R2 Resource Consultants 1998).

Figure Pass-7. Relationship between maximum velocity (calculated from hydraulic head) and mortality of juvenile salmonids measures at dams in the Pacific Northwest. Plotted curve is for dams with deep spilling basins and without flow deflectors. (Source: R2 Resource Consultants 1998).

Figure Pass-8. Intake screening facility at Tacoma Headworks Diversion dam (Source: Tacoma Public Utilities)

Figure Pass-9. Black River pumping station facility site plan. (Source: Harza 1995).

Figure Pass-10. Black River pumping station upstream fish passage facility. (Source Harza 1995).

Figure Pass-12 Known anthropogenic barriers in the Lower Green River, Puget Sound and Green/Duwamish Estuary sub-watersheds

Figure Pass-13. Black River pumping station downstream fish passage facility. (Source: Harza 1995).

Figure Pass-14. Hatchery rack at Soos Creek hatchery, RM 0.7, March 2, 2000 looking downstream and looking upstream. (Source: R2 Resource Consultants).

Figure Pass-15. Diversion weir and fish ladder at Soos Creek hatchery, RM 0.7, March 2 2000 (Source: R2 Resource Consultants).

Table Pass-1. Howard Hanson Reservoir Pool Physical characteristics at various pool elevations (USACE 1998).					
Pool Elevation (feet MSL)	**Surface Area (acres)**	**Volume (acre-feet)**	**Length (miles)**	**Perimeter (miles)**	**Description**
1,035	0	0	0	0	Run of River
1,070	100	1,200	1.5	3.1	Turbidity Pool
1,100	255	6,300	2.8	6.8	
1,130	560	17,265	3.9	11.2	
1,141	763	25,400	4.3	12.2	Conservation Pool
1,147	871	30,400	4.6	13.5	Drought Pool

Table Pass-2. Tag detection success rate at the forebay for salmoninds released into Howard Hanson Reservoir in 1995.				
Species	**Pool Level**	**Number Released**	**Number To Forebay**	**Detection Rate**
Coho	low	36	17	47%
Steelhead	low	36	17	47%
Coho	mid	36	14	38%
Steelhead	mid	36	26	72%
Chinook	high	17	6	35%
Coho	high	38	28	73%
Steelhead	high	34	30	88%

Table Pass-3. Average withdrawal at TPU Headworks as a percentage of mean daily flow during the period when juvenile salmonids are migrating downstream (Source: TPU 2000).			
Month	**Average Daily Flow (Cfs)**	**Average Withdrawal (Cfs)**	**Percent Of Daily Flow Withdrawn**
March	1,819	89.3	5%
April	1,922	88.3	5%
May	1,806	93.3	5%
June	1,208	106.7	9%

Table Pass-4. Recorded temperature conditions relative to water quality standards, NMFS habitat criteria for migration and rearing and potential lethal limits at various locations within the mainstem Green River.							
Location	**Max. Recorded Temperature**	**Nmfs Properly Functioning[1]**	**Exceeded ?**	**State Wq Standard**	**Exceeded?**	**Potential Lethal**	**Exceeded?**
RM 69	>60 ^oF[3]	50-57 ^oF	Yes	60.8 ^oF	unknown	73 - 84 ^oF	unknown
RM 64.5	62-64 ^oF[4]	50-57 ^oF	Yes	60.8 ^oF	Yes	73 - 84 ^oF	No
RM 60.8	65 ^oF[4]	50-57 ^oF	Yes	60.8 ^oF	Yes	73 - 84 ^oF	No
RM 41.5	73.4 ^oF[4]	50-57 ^oF	Yes	64 ^oF	Yes	73 - 84 ^oF	Yes
RM 35	74.3 ^oF[4]	50-57 ^oF	Yes	64 ^oF	Yes	73 - 84 ^oF	Yes
RM 32	64-72.5 ^oF[5]	50-57 ^oF	Yes	64 ^oF	Yes	73 - 84 ^oF	No
RM 27	72.5 ^oF[4]	50-57 ^oF	Yes	64 ^oF	Yes	73 - 84 ^oF	No
RM 20	73.4 ^oF[4]	50-57 ^oF	Yes	64 ^oF	Yes	73 - 84 ^oF	Yes
RM 18.3	>64 ^oF[6]	50-57 ^oF	Yes	64 ^oF	Yes	73 - 84 ^oF	unknown
RM 14	>64 ^oF[6]	50-57 ^oF	Yes	64 ^oF	Yes	73 - 84 ^oF	unknown
RM 12.5	73.4-75.2 ^oF[4]	50-57 ^oF	Yes	64 ^oF	Yes	73 - 84 ^oF	Yes

[1]NMFS 1999.
[2]Bjornn and Reiser 1991; Caldwell 1994; MacDonald et al. 1991.
[3]USACE 1998.
[4]Caldwell 1994.
[5]Unpublished data from USGS cited in Caldwell 1994.
[6]WDOE 1998.

Table Pass-5. Results of temperature monitoring conducted on the mainstem Green River in 1992 (from Caldwell 1994).				
Location	**Maximum Equilibrium Temperature in July And August**	**Hours Over 64^{o}f**	**Percent of Total Time Over 64 ^{o}f in August**	**Maximum Equilibrium Temperature in September**
RM 41.5	73.4 ^oF	383	30%	66.2 ^oF
RM 35	74.3 ^oF	663	45%	68 ^oF
RM 27	72.5 ^oF	621	46%	ND
RM 20	73.4 ^oF	839	57%	68 ^oF
RM 13	73.4-75.2 ^oF	1140	71%	68 ^oF

ND=No data.

Figure PASS-1

Known Anthropogenic Barriers

Upper Green River Subwatershed

NO EXPRESS OR IMPLIED WARRANTIES; NO WARRANTY OF MERCHANTABILITY; NO WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE.

There are not express or implied warranties for this data, or any service furnished herein. There is no warranty of merchantability for this data's accuracy or its depiction of barrier type or location. This data is not warranted as fit for a particular purpose. Depiction of this data in text, graphical or other format(s) requires attribution of the Washington State Conservation Commission/Northwest Indian Fisheries Commision as source. Any modification of this data requires notification and identification of the parts modified. Use of this data is explicit acceptance of these terms and conditions.

Temperature barriers based upon the 1998 DOE 303-D listing. The other barriers may or may not coincide with the 303-D barrier location.

Note:
303-D barrier data are offset slightly for clarity purposes.

Data Sources:
Salmonid Barrier:
Ronald McFarlane, NWIFC, September 2000

Transportation:
Washington State Department of Natural Resources, September 2000
Resolution scale: 1:24000

Hydrography:
KC/DOE Hydrography Project, 1997
KC Wetlands Inventory, 1990
KC Standard WRIA & Subbasin Boundaries
Resolution scale: 1:24000

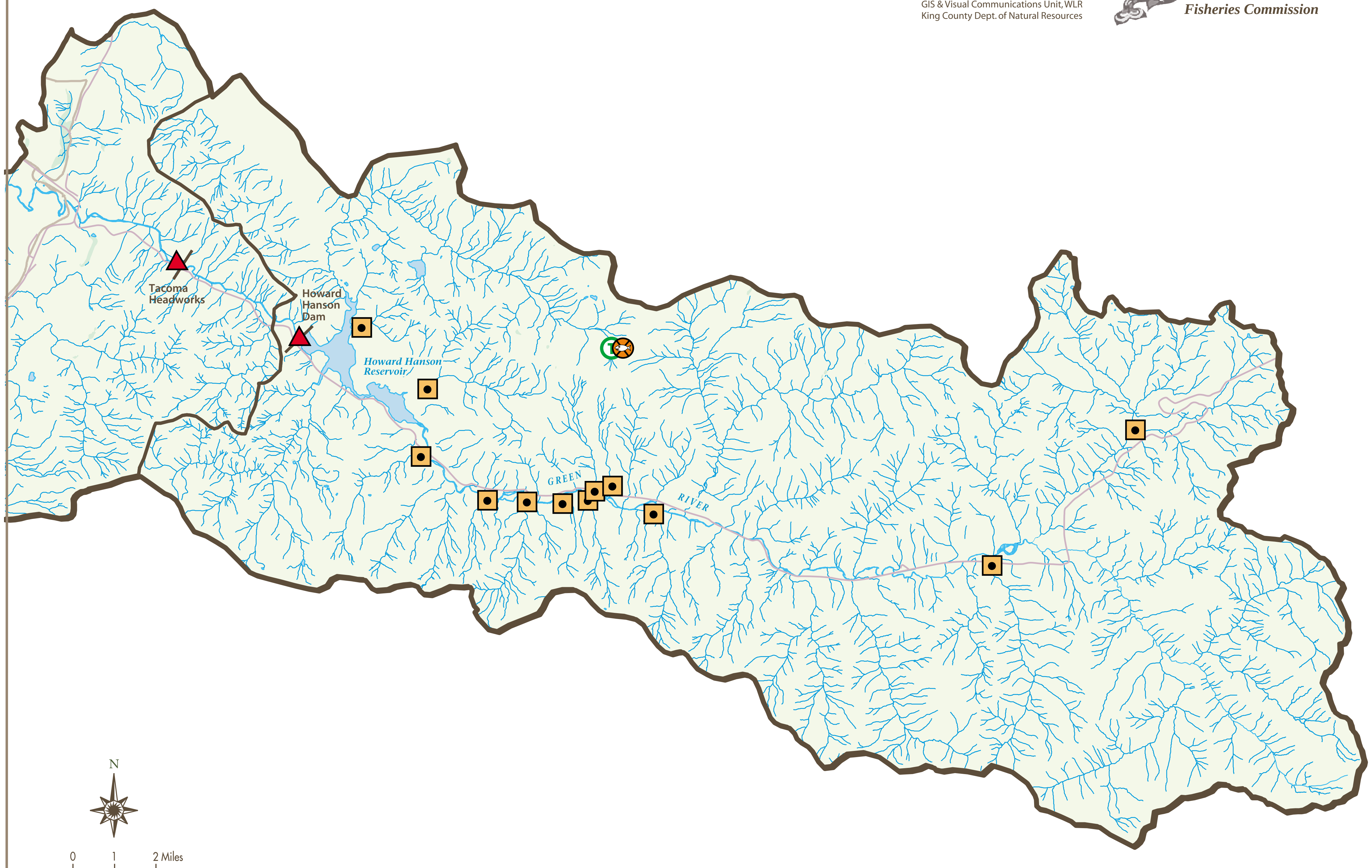
File Name:
0011FishBarrierUPPER.ai sk

Produced by:
GIS & Visual Communications Unit, WLR
King County Dept. of Natural Resources

King County Department of Natural Resources

Washington State Conservation Commission

Northwest Indian Fisheries Commission



303(d) Listed
Culvert
Dam
Dam with Passage
Dike/Levee
Flapgate
Flow
Temperature
Primary Roads
Secondary Roads
Railroad
WRIA Boundary
Subwatershed Boundary
Streams
Lakes/Major Waterways
Marsh/Wetland, etc.
Sewage Lagoons

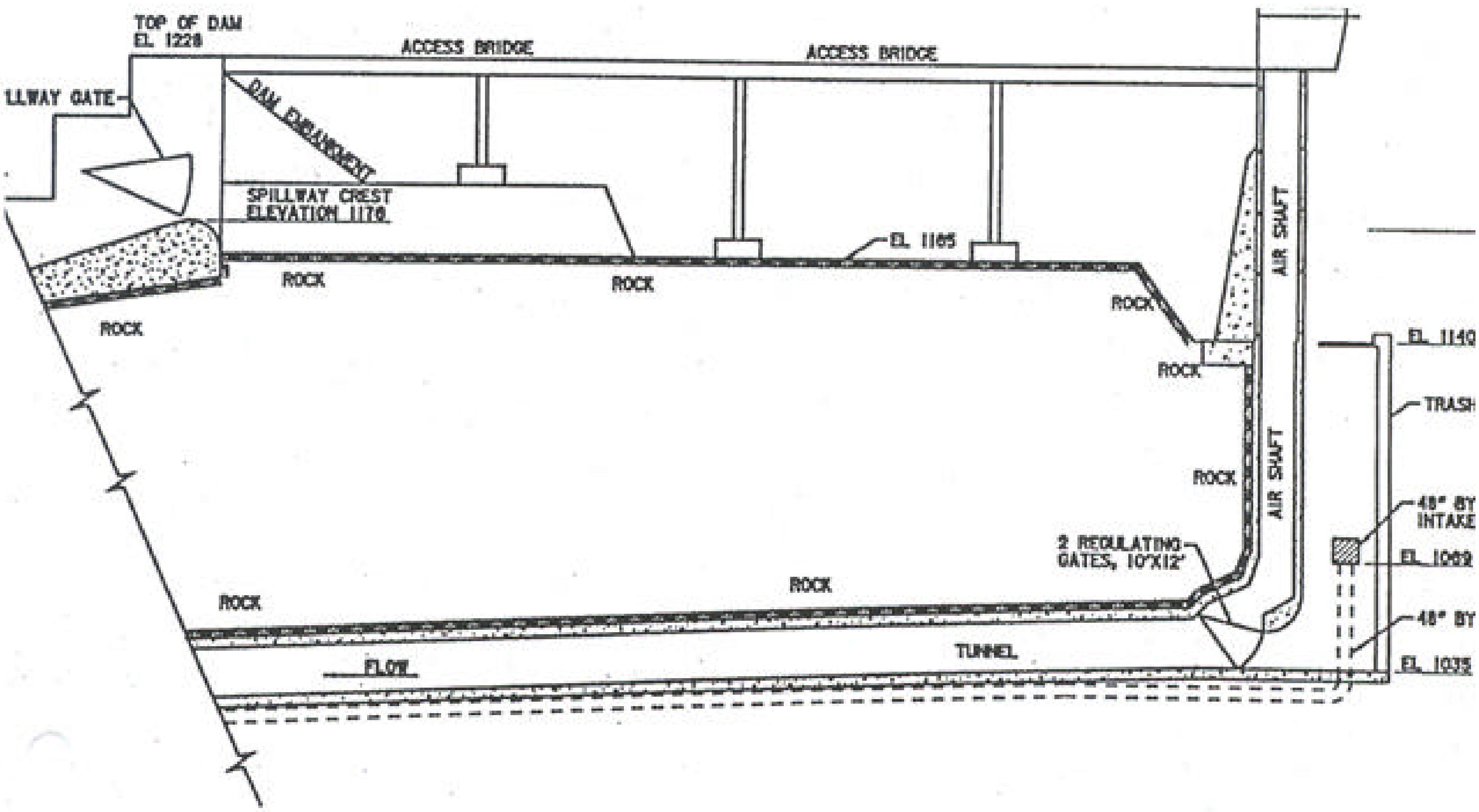


Figure Pass-2. Cross-section of Howard Hanson Dam (Source: USACE 1998).

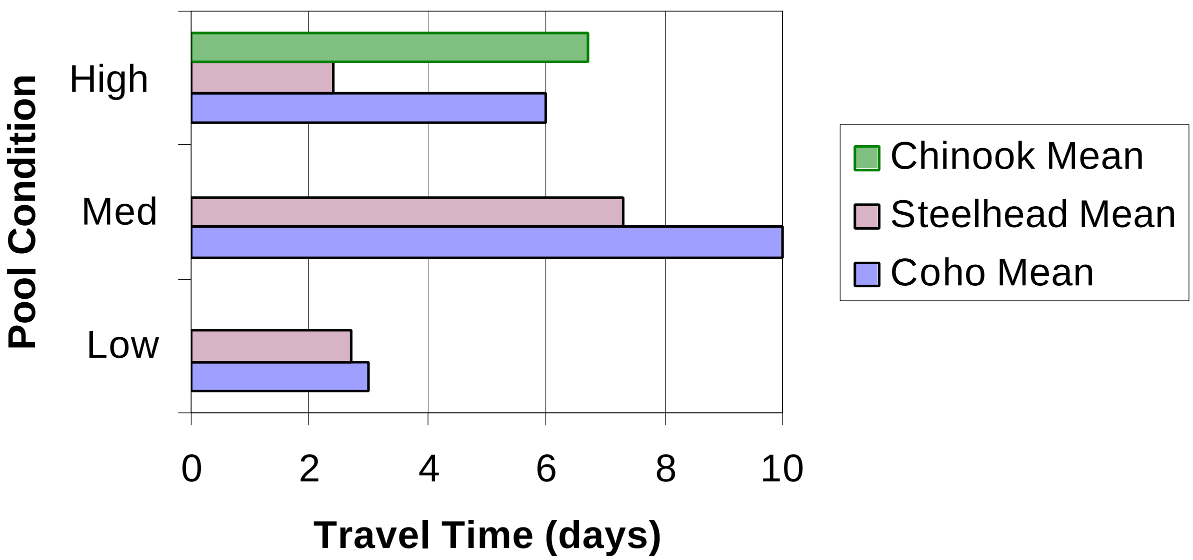
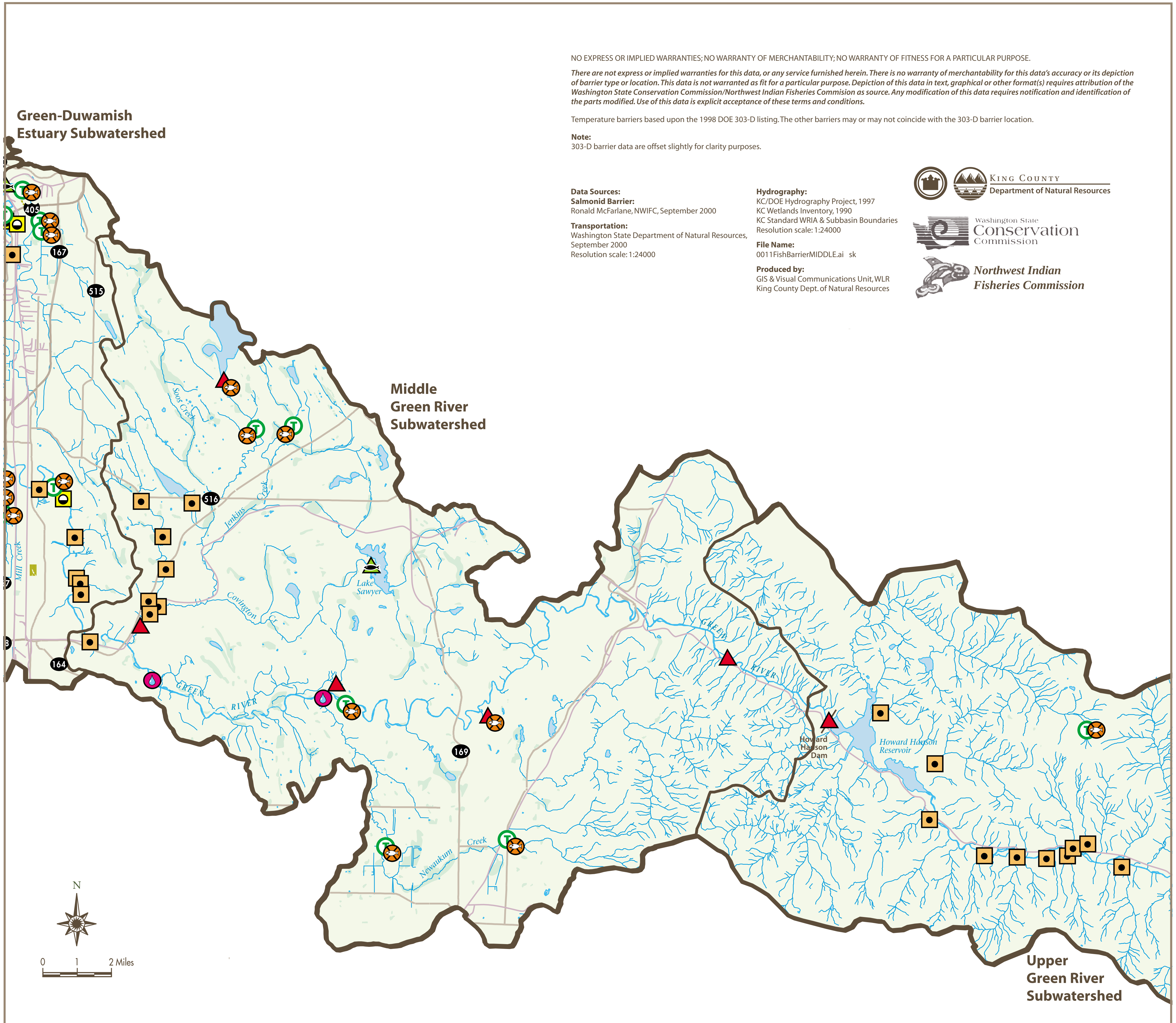


Figure Pass-3: Mean travel times of chinook, coho, and steelhead smolts through three pool conditions at Howard Hanson Dam (Source: USACE 1998)

Figure PASS-4

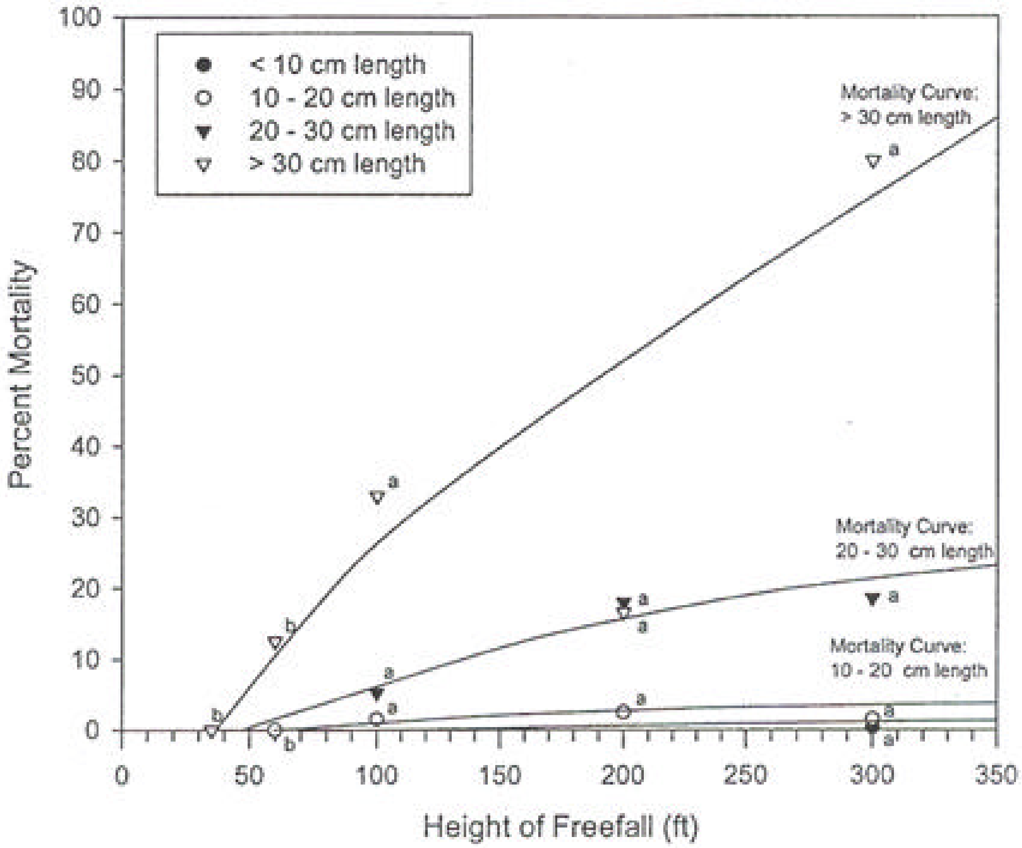
Known Anthropogenic Barriers

Middle Green River Subwatershed

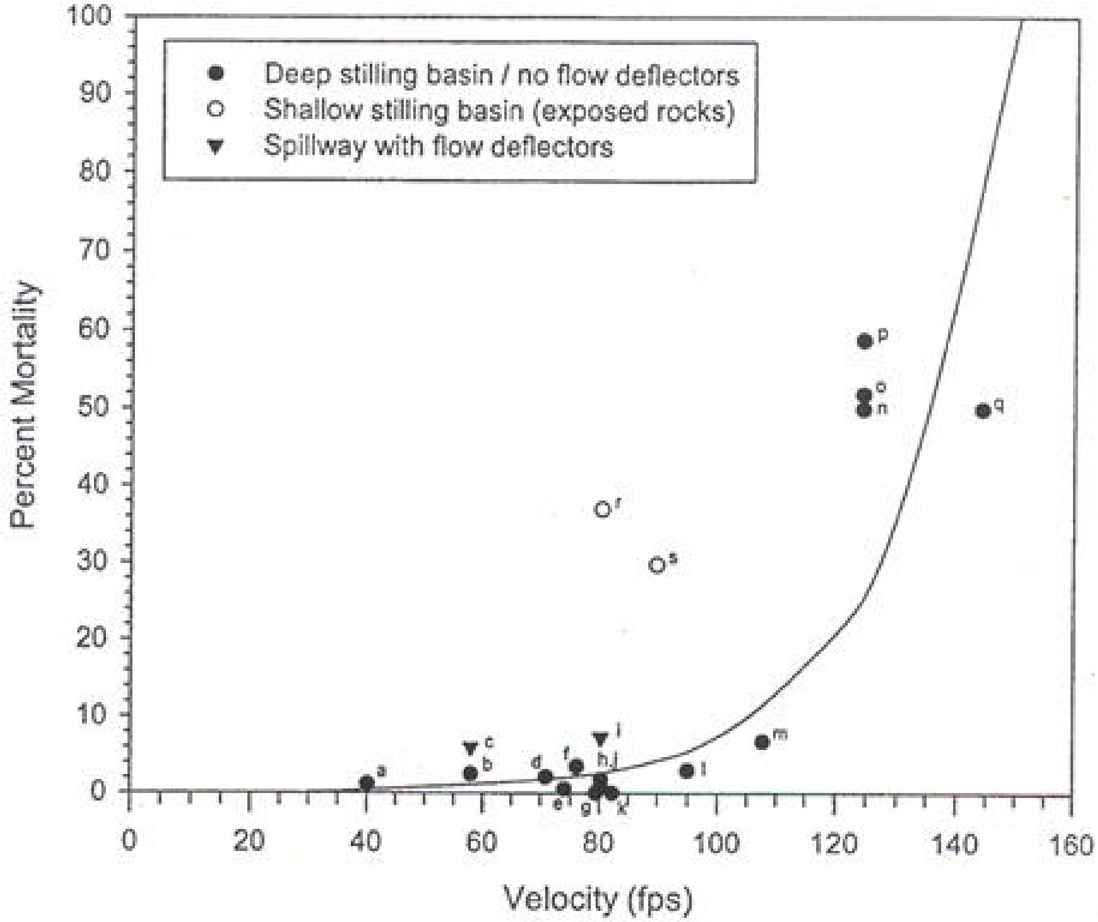


- 303(d) Listed
- Culvert
- Dam
- Dam with Passage
- Dike/Levee
- Flapgate
- Flow
- Temperature
- Primary Roads
- Secondary Roads
- Railroad
- WRIA Boundary
- Subwatershed Boundary
- Streams
- Lakes/Major Waterways
- Marsh/Wetland, etc.
- Sewage Lagoons

Figure Pass-5. Tacoma Headworks diversion dam, RM 61. (Source: Tacoma Public Utilities).



Pass 6 Relationship between freefall height and mortality of salmonid fish. Mortality curve is near zero for fish less than 10 cm in length. Mortality estimates obtained from: (a) aerial drop of coho salmon and rainbow trout from helicopter, Regenthal 1956; and (b) aerial drop of atlantic salmon from tower, Sweeny and Ritchie 1981. (Source: R2 Resource Consultants)



Pass 7 Relationship between maximum velocity (calculated from hydraulic head) and mortality of juvenile salmonids measured at dams in the Pacific Northwest. Plotted curve for dams with deep spilling basins and without flow deflectors. (Source: R2 Resource Consultants)

List of Dams (including type of spillway and literature source)

a - Seton Creek Hydroelectric Project, BC; siphon and submerged jet (Andrew and Geen 1958)
b - Bonneville Dam; ogee with no flow deflectors (Holmes 1952; Johnsen and Dawley 1974)
c - Bonneville Dam; ogee with flow deflectors (Johnsen and Dawley 1974)
d - The Dalles; ogee (Normandeau Associates 1996)
e - McNary Dam; ogee and bucket (Schoeneman et al. 1961)
f - Big Cliff Dam; ogee and bucket (Schoeneman et al. 1961)
g- Little Goose Dam; ogee (Iwamoto et al. 1994)
h - Lower Monumental Dam; ogee with no flow deflectors (Long et al. 1975; Muir et al. 1995)
i - Lower Monumental Dam; ogee with flow deflectors (Muir et al. 1995)
j - Lower Granite Dam; ogee (Park and Achord 1987)
k - John Day Dam; ogee (Raymond and Sims 1980)
l - Alder Dam, WA; flume and freefall (Schoeneman 1959)
m - Glines Dam, WA; freefall (Shoeneman and Junge 1954)
n - Cleveland Dam, BC; ski jump and horizontal jet (Vernon and Hourston 1957)
o - Baker Dam, WA; ski jump to chute (Hamilton 1955)
p - Baker Dam, WA; ski jump to chute (Regenthal 1955)
q- Yale Dam, WA; chute (Schoeneman et al. 1955)
r- Elwha Dam, WA; chute (Shoeneman and Junge 1954)
s - Condit Dam, WA; chute (Seiler and Neuhauser 1985)

Figure Pass-8. Backup intake screen, Tacoma Headworks diversion dam. (Source: Tacoma Public Utilities)

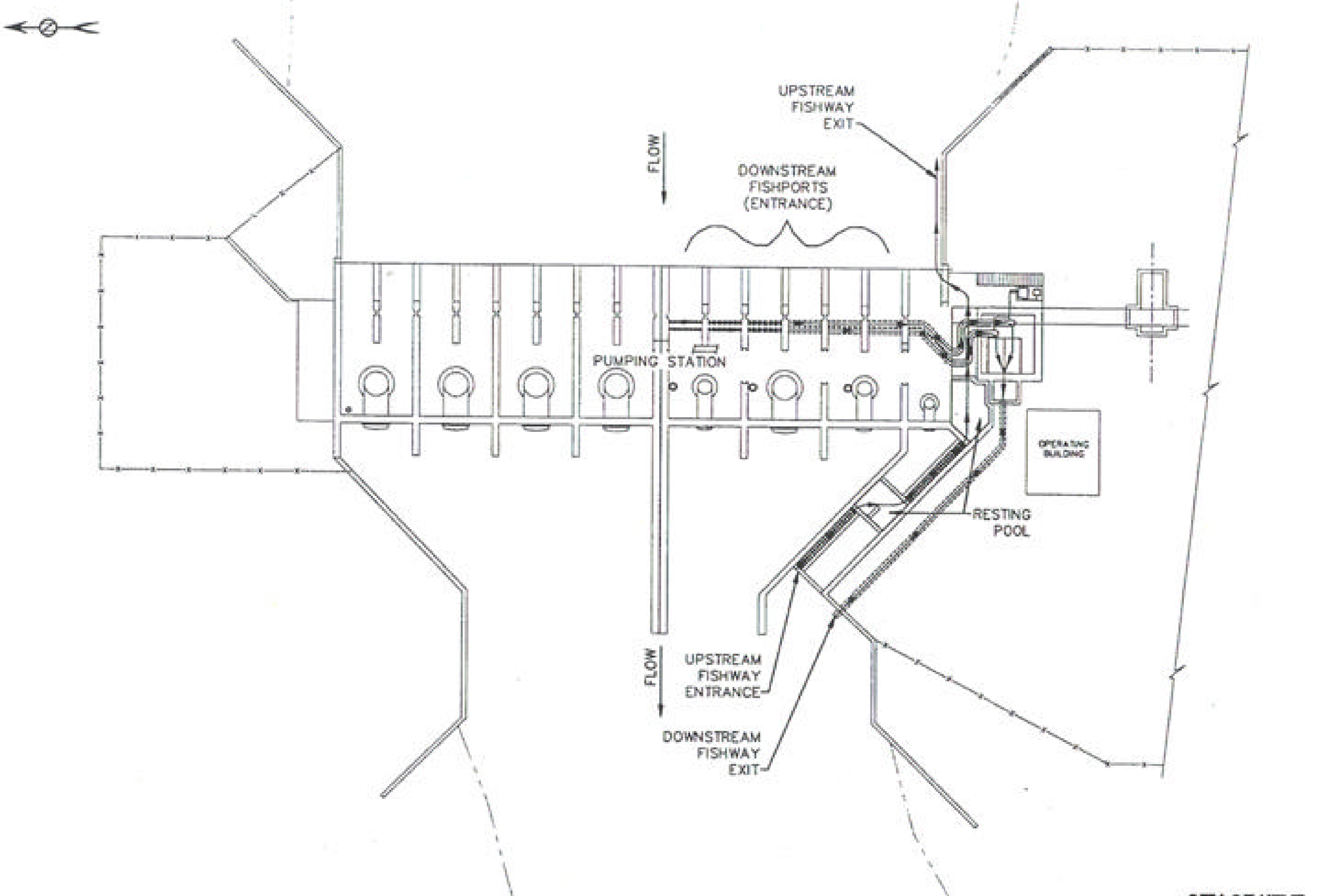


Figure Pass-9

BLACK RIVER PUMPING PLANT
FACILITY SITE PLAN

CITY OF KENT

MILL CREEK
FISHERIES STUDY

HARZA NORTHWEST, INC.
Engineers and Scientists

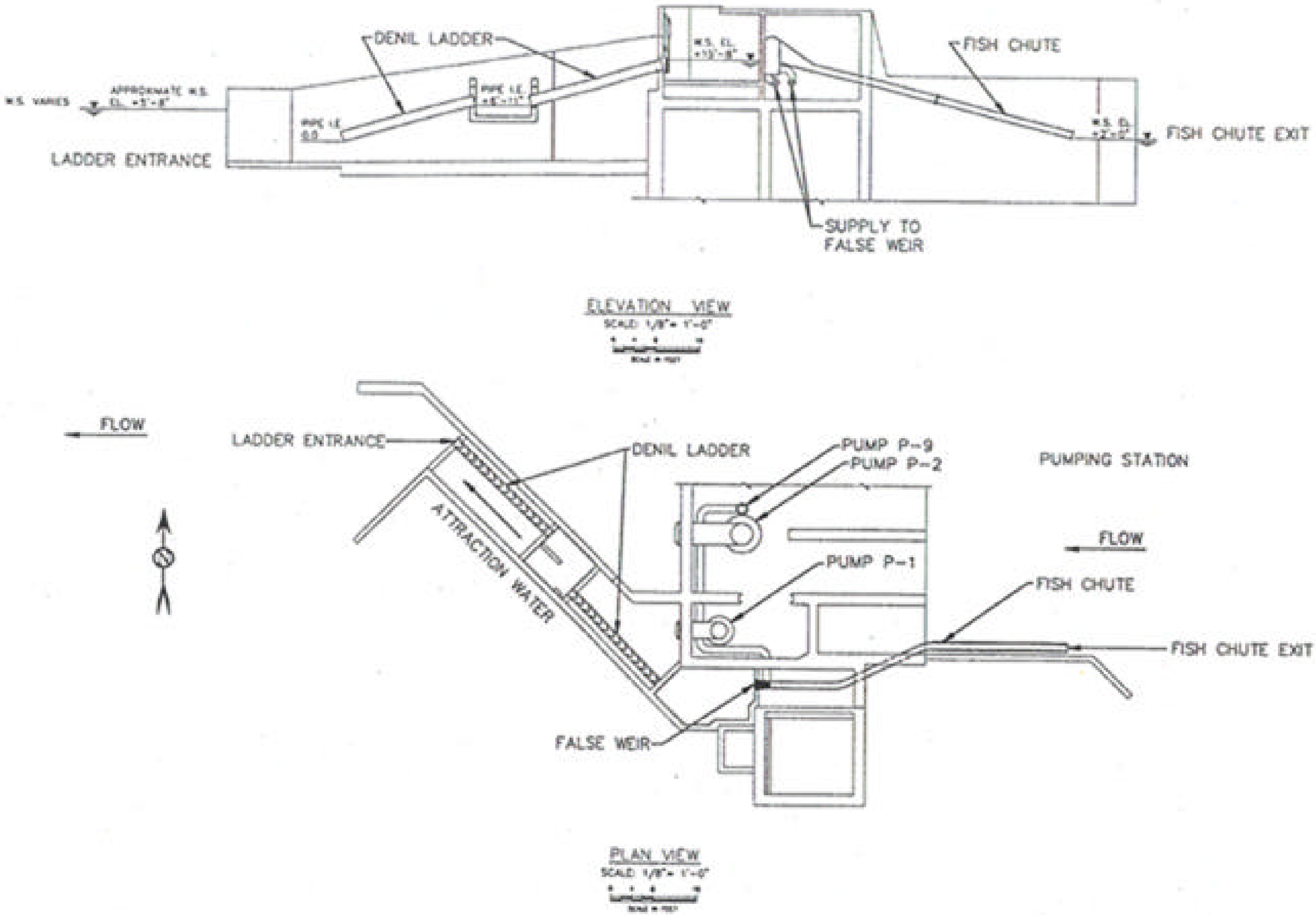


Figure Pass-10

BLACK RIVER PUMPING PLANT
UPSTREAM FISH PASSAGE FACILITY

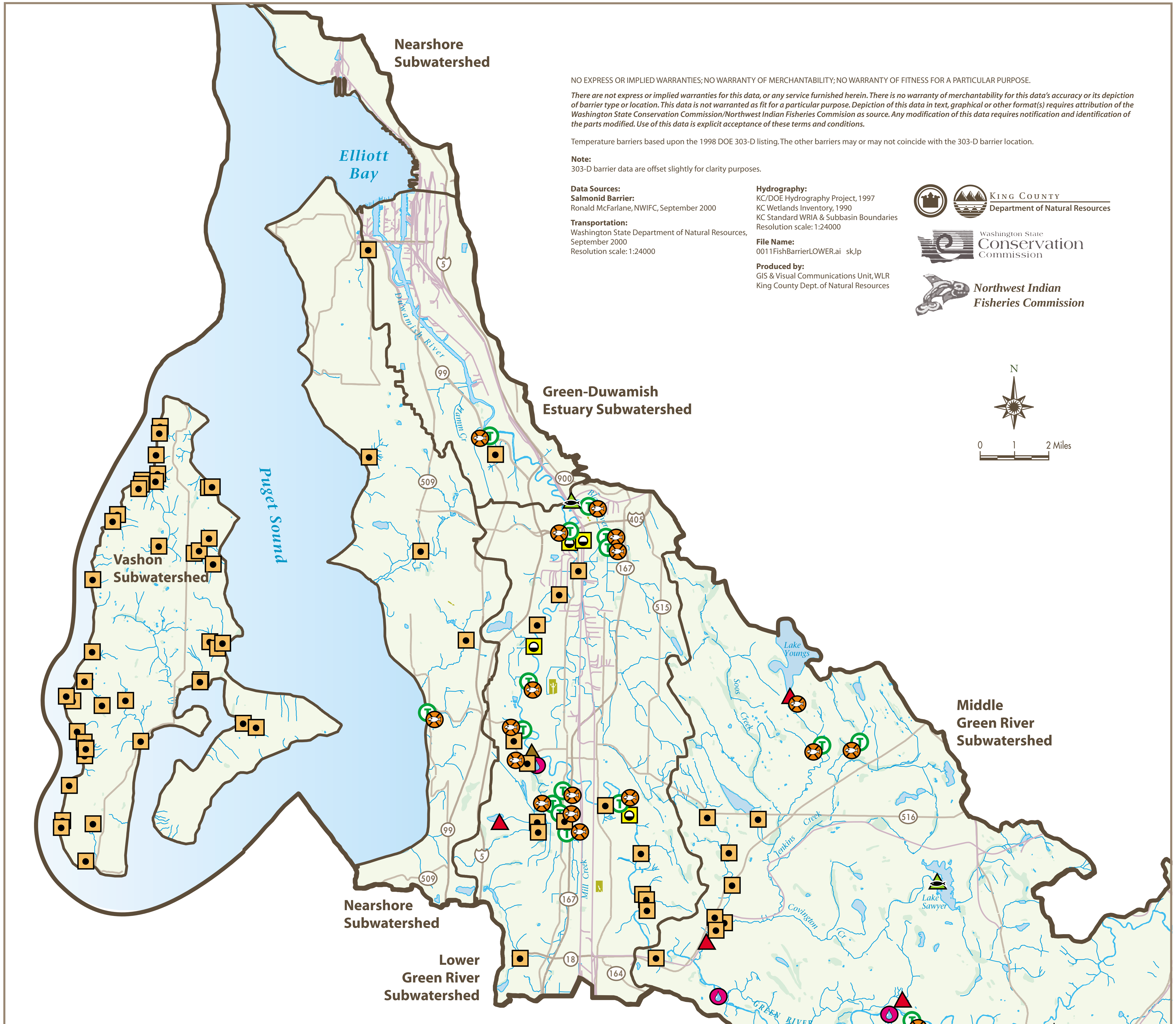
CITY OF KENT
MILL CREEK
FISHERIES STUDY

HARZA NORTHWEST, INC.
Engineers and Scientists

Figure PASS-12

Known Anthropogenic Barriers

Lower Green River, Puget Sound and Green/Duwamish Estuary Subwatersheds



NO EXPRESS OR IMPLIED WARRANTIES; NO WARRANTY OF MERCHANTABILITY; NO WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE.

There are not express or implied warranties for this data, or any service furnished herein. There is no warranty of merchantability for this data's accuracy or its depiction of barrier type or location. This data is not warranted as fit for a particular purpose. Depiction of this data in text, graphical or other format(s) requires attribution of the Washington State Conservation Commission/Northwest Indian Fisheries Commision as source. Any modification of this data requires notification and identification of the parts modified. Use of this data is explicit acceptance of these terms and conditions.

Temperature barriers based upon the 1998 DOE 303-D listing. The other barriers may or may not coincide with the 303-D barrier location.

Note:
303-D barrier data are offset slightly for clarity purposes.

Data Sources:
Salmonid Barrier:
Ronald McFarlane, NWIFC, September 2000

Transportation:
Washington State Department of Natural Resources, September 2000
Resolution scale: 1:24000

Hydrography:
KC/DOE Hydrography Project, 1997
KC Wetlands Inventory, 1990
KC Standard WRIA & Subbasin Boundaries
Resolution scale: 1:24000

File Name:
0011FishBarrierLOWER.ai sk,lp

Produced by:
GIS & Visual Communications Unit, WLR
King County Dept. of Natural Resources

King County
Department of Natural Resources

Washington State
Conservation
Commission

Northwest Indian Fisheries Commission

- 303(d) Listed
- Culvert
- Dam
- Dam with Passage
- Dike/Levee
- Flapgate
- Flow
- Temperature
- Primary Roads
- Secondary Roads
- Railroad
- WRIA Boundary
- Subwatershed Boundary
- Streams
- Lakes/Major Waterways
- Marsh/Wetland, etc.
- Sewage Lagoons

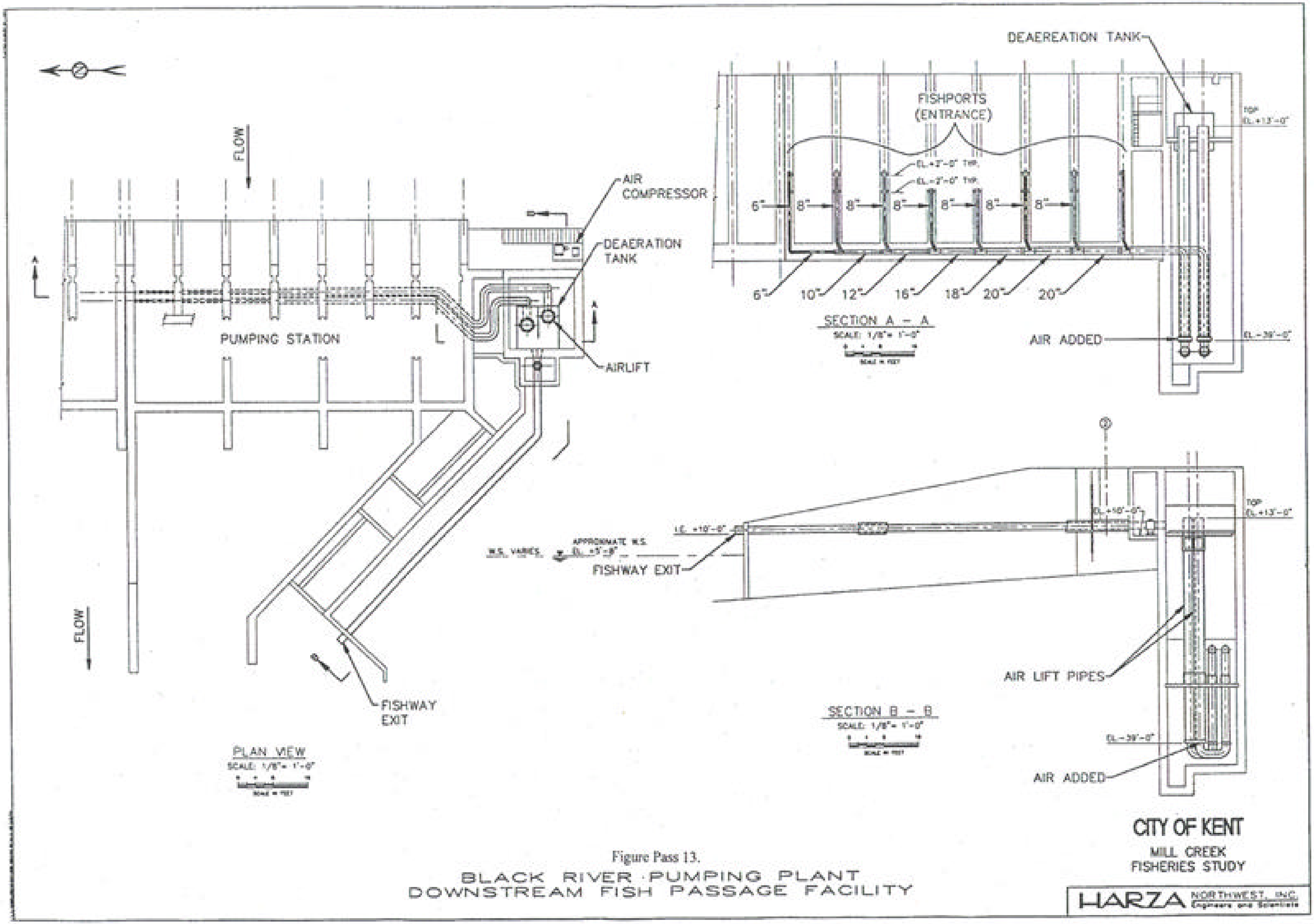


Figure Pass 13.
BLACK RIVER PUMPING PLANT
DOWNSTREAM FISH PASSAGE FACILITY

Figure Pass 14. Hatchery rack at Soos Creek hatchery, RM 0.7, March 2, 2000 looking downstream (above) and looking upstream (below).

Figure Pass 15. Diversion weir and fish ladder at Soos Creek hatchery, RM 0.7, March 2, 2000 (Source R2 Resource Consultants).

2.6 NON-NATIVE SPECIES

2.6 NON-NATIVE SPECIES

EXECUTIVE SUMMARY

Non-native plant and animal species are of concern to efforts to help protect and recover salmonids in the Green River Watershed, because non-native species can potentially affect native species by occupying similar ecological niches and competing for food and habitat; inhibiting reproduction; interbreeding with native species; being sources of parasites and pathogens; and even modifying, reducing, or eliminating habitat used by native species (Moyle et al. 1986). In the Green River Watershed, there is not a program that routinely monitors for non-native species, but rather they are discovered as a part of other programs. One exception, the Puget Sound Expedition, documented non-indigenous marine invertebrate and plant species in all of Puget Sound, including Elliot Bay. This survey found 38 non-native species in the sound, although it is not known what proportion of these species were found in Elliott Bay. Observations indicate that relatively few non-native fish species occur in Elliott Bay, the Green/Duwamish Estuary, or adjacent to the mainstem Green River upstream of tidal influence. Perhaps the most notable non-native fish species that sometimes occurs in the Green River is the adult Atlantic salmon (*Salmo salar*) that swim up the river after having escaped from the commercial net-pen fishery in Puget Sound. King County maintains a database of Atlantic salmon observations in the Green River (Nelson 2000).

Other non-native fish species other than salmonids that could potentially occur in the Green River include warmwater game fish that are found in several of the lakes that drain to tributaries of the Green River (WDFW 1999). These species include yellow perch (*Perca flavescens*), black crappie (*Pomoxis nigromaculatus*), pumpkinseed (*Lepomis gibbosus*), brown bullhead (*Ameiurus nebulosus*), smallmouth bass (*Micropterus dolomieui*), and largemouth bass (*Micropterus salmoides*). Although these warmwater game fish typically prefer waters which are relatively warm and slow moving several of these fish are occasionally observed in Soos Creek at the Soos Creek Fish Hatchery (Wilson 2000).

Relatively few non-native animal species other than fish potentially occur in or adjacent to the Green River. Nutria (*Myocastor coypus*), an aquatic mammal, is believed to occur in the Green River (Cassidy et al. 1997; Johnson and Cassidy 1997). Other non-native species that are potentially in the Green River include: the slider turtle (also known as the red-eared slider) (*Trachemys scripta*); snapping turtle (*Chelydra serpintina*); painted turtle (*Chrysemys picta*), which, although native to most of Washington state, is believed to have extended its range to the coast as a result of introductions (MELP 1998); spiny softshell turtle (*Apalone spiniferus*); bullfrog (*Rana catesbeiana*); green frog (*Rana clamitans*); Asian clam (*Corbicula fluminea*); and New Zealand mudsnail (*Potamopyrgus antidarium*). In addition to the species listed above, other non-native animals in and adjacent to the Green River include cattle, horses, and other livestock.

A number of non-native plant species are known to occur within the riparian zone of the Green/Duwamish estuary, the mainstem Green River, and its major tributaries. Of most concern along the river are a variety of non-native herbaceous and shrubby plants that tend to form dense colonies, which exclude the establishment of a more diverse or natural vegetative community. Species of particular concern include a variety of pasture grasses, reed canary grass (*Phalaris* *arundinacea*), Himalayan and evergreen blackberry (*Rubus discolor* and *R. laciniatus*), and Japanese knotweed (*Polygonum cuspidatum*).

KEY FINDINGS

The key findings on non-native plants and animals in the Green/Duwamish estuary, mainstem Green River, and major tributaries are listed below:

- Although adult Atlantic salmon, which have escaped from the commercial net pen industry, occasionally swim into the estuary and up the Green River, no juvenile Atlantic salmon have been observed in the system.

- Non-native warmwater fish are known to be present in lakes that drain to the mainstem Green River, but observations of these fish in the river are limited.

- Nutria and bullfrogs are the only non-native aquatic animal species other than fish observed in the Green River watershed upstream of the tidally influenced zone.

- In the Green/Duwamish Estuary, three non-native benthic invertebrates are known to occur - the amphipod *Grandidierella japonica,* the tanaid *Sinelobus stanfordi,* and the cumacean *Nippoleucon hinumensis.*

- Some riparian areas are dominated by dense colonies of non-native vegetation, such as blackberry, reed canary grass, and Japanese knotweed.

DATA GAPS

- No program exists that routinely monitors for or documents the presence and location of non-native species in the Green River watershed.

- The overall implications of non-native species invasions are not well understood.

INTRODUCTION

Non-native species are organisms whose natural distribution did not originally include the area in which they are now found. Non-native species are also commonly referred to as non-native, non-indigenous, or introduced species. Sometimes they also are known as invasive species, alien species, or weeds. In WRIA 9 freshwater environment, non-native species identified to date include organisms that originated in Europe, Asia, and the eastern and southern regions of the American continents. For example, in North America, the Rocky Mountains are a physical barrier that naturally separates the ranges of many plants and animals. A species that is native to only the eastern United States is considered an non-native species when it occurs in the west, and conversely, many native western species are non-native in the eastern states.

Species can be introduced to areas outside their natural range through intentional transfers, movements through altered waterways (i.e., canals or diversions) or land cover (i.e., conversion of forest to pasture), and as a result of accidental or unintentional releases. In the Pacific

Northwest, non-native aquatic species have been introduced primarily through: 1) fishery management stocking; 2) intentional introductions of gamefish by anglers; 3) intentional or unintentional baitfish liberation by anglers; and 4) bilge pumping of ballast water in estuaries and large rivers (Spence et al. 1996). In the Pacific Northwest, the first recorded stocking of non-native fish was in 1880 when German carp were brought in to stock a nursery pond in Troutdale, Oregon (WDFW 1999). Other fish species soon followed, and many were brought by rail under the direction of the U.S. Fish Commission as part of an effort to provide enhanced recreational angling opportunities (WDFW 1999).

Human-caused alterations to habitats and habitat-sustaining functions can produce favorable new habitats in areas that were otherwise ecologically unsuited to non-native species (MacCrimmon and Robbins 1975, Spence et al. 1996). An introduced species may fare better than native species when conditions deviate significantly from historic. For example, dams can transform riverine habitat from free-flowing to lacustrine conditions, change the flow regime from relatively steady to rapidly fluctuating flows, alter characteristic water temperatures and dissolved oxygen concentrations, and disrupt sediment transport and deposition processes. Relatively small changes to a native species' environment may sometimes be sufficient to stress or weaken the native population and favor the introduced species, resulting in a significant shift in aquatic community structure. This community shift can also occur among native species.

Not all non-native species can persist as self-sustaining populations in new locations. Some non-native species are unable to successfully reproduce in the Pacific Northwest due to temperatures or other environmental factors that are unfavorable to their life history requirements. Species that do not successfully reproduce may be occasionally present, but otherwise, they do not persist in the region without continual reintroduction. However, some introduced species can thrive and outcompete native species directly even without changes to the latter's environment simply because they are better adapted or more adaptable.

POTENTIAL EFFECTS OF NON-NATIVE SPECIES

Aquatic ecosystems can be especially susceptible to invasion and alteration by non-native species, and the presence of non-native species in aquatic systems is sometimes used as an indicator of ecosystem degradation (Karr 1991). The presence of non-native species can negatively affect native species by occupying similar ecological niches and competing for food and habitat; inhibiting reproduction; interbreeding with native species; being sources of parasites and pathogens; and even modifying, reducing, or eliminating habitat used by native species (Moyle et al. 1986).

NON-NATIVE SPECIES POTENTIALLY OCCURRING IN THE GREEN RIVER WATERSHED

In the Green River Watershed, there is not a program that routinely monitors for non-native species, but rather they are discovered as a part of other programs. In the Green River Watershed, anthropogenic alterations have created several new distinct habitats, which could be favorable to self-sustaining populations of non-native species. These ecologically altered regions include: 1) areas of the riparian zone that have been converted from its original dense floodplain forest to cleared or developed land; 2) the approximately 32 miles of river that have been dredged and/or channelized; 3) the creation of numerous farm and residential fish ponds, which drain to the main river; and 4) the alternating riverine and lacustrine habitat upstream of the Howard Hanson Dam.

Relatively few non-native fish species are known to occur in or adjacent to the mainstem Green River upstream of tidal influence. Perhaps the most notable non-native species is the adult Atlantic salmon (*Salmo salar*) that swim up the Green River after having escaped from the commercial net-pen fishery in Puget Sound. King County maintains a fish distribution map of Atlantic salmon in the Green River (Nelson 2000).

In addition to escaped Atlantic salmon, other salmon species and stocks of salmon species have been introduced to the Green River and its tributaries. These introductions including kokanee and sockeye salmon (*Oncorhynchus nerka*), steelhead (summer and winter stocks) and rainbow trout (*O. mykiss*), chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), chum salmon (*O. keta*), cutthroat trout (*O. clarki*) and eastern brook trout (*Salvelinus fontinalis*). Of these six species, only the eastern brook trout is considered to be an non-native species in the Green River watershed and the historic presence of summer steelhead is not known.

- For the purposes of this assessment, released and existing kokanee, cutthroat, steelhead, rainbow trout, and chinook, coho, and chum salmon are not considered to be non-native species in the Green River. Information stocks of salmonids present in the Green River watershed is discussed in Part I: Chapter 3.

Non-native fish species other than salmonids that could potentially occur in the Green River include warmwater game fish that are found in several of the lakes that drain to tributaries of the Green River (WDFW 1999). These species include yellow perch (*Perca flavescens*), black crappie (*Pomoxis nigromaculatus*), pumpkinseed (*Lepomis gibbosus*), brown bullhead (*Ameiurus nebulosus*), smallmouth bass (*Micropterus dolomieui*), and largemouth bass (*Micropterus salmoides*). Warmwater game fish typically prefer waters which are relatively warm and slow moving.

Information on non-native animal species other than fish that could potentially occur in or adjacent to the Green River was compiled primarily from the USGS GAP Analysis of Washington (Cassidy et al. 1997), the Washington State Aquatic Nuisance Species Management Plan (WANSPC 1998), and interviews with local habitat and fisheries biologists. Potential non-native species in the Green River include: the slider turtle (also known as the red-eared slider) (*Trachemys scripta*); snapping turtle (*Chelydra serpintina*); painted turtle (*Chrysemys picta*), which, although native to most of Washington state, is believed to have extended its range to the coast as a result of introductions (MELP 1998); spiny softshell turtle (*Apalone spiniferus*); bullfrog (*Rana catesbeiana*); green frog (*Rana clamitans*); Asian clam (*Corbicula fluminea*); and New Zealand mudsnail (*Potamopyrgus antidarium*).

Nutria (*Myocastor coypus*), an aquatic mammal, is also believed to occur in the Green River (Cassidy et al. 1997; Johnson and Cassidy 1997). Although nutria is more abundant further south in Washington state, it first escaped here via a fur-farm along the Green River during a flood in 1935 (Johnson and Cassidy 1997).

In addition to the species listed above, other non-native animals in and adjacent to the Green River include cattle, horses, and other livestock. Although these animals are not aquatic, livestock pastures routinely provide access for the animals to streams and rivers for water. Because these animals congregate in herds, riparian areas that they frequent to access the water are often highly disturbed as a result of trampling and foraging.

A number of non-native plant species are found within the riparian zone of the Green River and some non-native plant species also occur within the lakes and waterways that drain to the river. Of most concern along the river are a variety of non-native herbaceous and shrubby plants that tend to form dense colonies, which exclude the establishment of a more diverse or natural vegetative community. These invasive plants species tend to become established in highly disturbed sites that have been modified either by clearing activities or by flooding. Species of particular concern include a variety of pasture grasses, reed canary grass (*Phalaris arundinacea*), Himalayan and evergreen blackberry (*Rubus discolor* and *R. laciniatus*), and Japanese knotweed (*Polygonum cuspidatum*). Other non-native plants that are more common to the lakes that drain to the Green River than to the river itself are purple loosestrife (*Lythrum salicaria*) and Eurasian watermilfoil (*Myriophyllum spicatum*). On the Washington State list of freshwater plant species that are aquatic nuisance species, only purple loosestrife (*Lythrum salicaria*), an emergent plant species has been identified in Green River watershed.

The following Sections briefly review known observations by subwatershed of non-native fish, animal, and plant species in and along the mainstem Green River.

UPPER GREEN RIVER SUBWATERSHED (RM 64.5 – RM 93)

FISH

The only non-native fish known to occur in the Upper Green River subwatershed is the eastern brook trout. Eastern brook trout were stocked by the state in the Green River and several of its tributaries as early as 1919 (WDFG 1920). These early records are not specific as to the locations of these releases.

Eastern brook trout have been documented to currently occur in two tributaries of Howard Hanson Reservoir - Page Mill Creek and Sunday Creek (Goetz, 2000). Sunday Creek drains Lizard Lake, which has not been stocked with eastern brook trout for many years, but which is believed to support a reproducing population of brook trout (Pfeifer 2000). Brook trout are usually of most concern where they co-occur with native bull trout. Bull trout and brook trout, two related char species, are thought to directly compete for limited habitat resources. Brook trout tend to be more aggressive than bull trout and may displace bull trout from optimal foraging areas. In addition to direct competition for resources, brook trout pose an additional threat to bull trout since the two species are capable of interbreeding (Leary et al. 1983, Scott and Crossman 1973, Markle 1992). The hybrid offspring typically do not reproduce (Leary et al. 1991), however, eastern brook trout tend to eventually replace bull trout when interbreeding occurs, as a result of differences in their life history strategies (e.g., brook trout mature earlier than bull trout) (Leary et al. 1991). Numerous surveys have failed to locate any bull trout in the

Upper Green River Watershed (Jeff Light 2000; USFS 1998; Watson and Hillman 1997; Goetz 1998).

OTHER ANIMALS

No non-native animals other than fish are known to occur in or adjacent to the Green River in the Upper Green River subwatershed.

PLANTS

Non-native plant species often colonize new habitats in disturbed areas such as roadsides, right-of-ways, clearcuts and gravel pits. The upper Green River subbasin has not been surveyed for non-native plant species as of the date of this report. However, the following Non-native plant species have been documented in this subwatershed: spotted knapweed, Scot's broom, Bull thistle, Poison hemlock, common St. John's wort, oxeye daisy, white campion, tansy ragwort and flannel mullein (USFS 1996). Non-native aquatic freshwater plants are not believed to be prevalent in the Upper Green River subwatershed (for example, see Shapiro and Associates 1985).

MIDDLE GREEN RIVER SUBWATERSHED (RM 31 – RM 64.5)

FISH

Adult Atlantic salmon that have escaped from the commercial aquaculture net-pen industry in Puget Sound have been seen as far upstream as RM 40 in the Middle Green River subwatershed (Tom Cropp 2000), and occasional adult Atlantic salmon have been captured at the hatchery trap at the Soos Creek Hatchery. The WDFW hatchery manager indicated that he has seen only 1 or 2 Atlantic salmon at the fish rack within the last ten years (Wilson 2000).

Atlantic salmon are farmed in marine net pens in both Washington and British Columbia waters. The salmon net pen industry in British Columbia is ten times larger than Washington (Amos and Appleby 1999). Annual escapes from British Columbia pens are estimated be approximately 60,000 fish. Estimated escapes from Washington state marine net pens in 1996, 1997, and 1999 were a reported 107,00, 369,00, and 115,000 Atlantic salmon, respectively (Amos and Appleby 1999). Although previous attempts had been made by the state to establish Atlantic salmon in several state waters (not including any waters in King County), these efforts were unsuccessful (Amos and Appleby 1999). Naturally-produced Atlantic salmon in Pacific coast streams were not discovered until 1998 and 1999, when juveniles were found in streams on Vancouver Island, British Columbia. It is unknown if juvenile Atlantic salmon that are the progeny of spawning Atlantic salmon adults in Pacific Northwest rivers are capable of maturing and returning to spawn in the wild (Amos and Appleby 1999). To date, no juveniles or naturally-produced Atlantic salmon have been identified in the Green River (Warner 2000; Cropp 2000).

Interviews with regional biologists identified no other known observations of non-native fish species in the mainstem Green River between RM 31 and RM 64.5. However, the Middle Green River subwatershed contains several lakes known to support non-native warmwater species (Section 5.2.6), thus it is possible that such species are sometimes able to access the tributaries and mainstem. However, no records or observations of warmwater gamefish in the mainstem Green River were located.

OTHER ANIMALS

Other than domestic livestock, no non-native non-fish animals have been recently reported to occur in or adjacent to the Green River in the Middle Green River subwatershed. It is possible, however, that nutria (Johnson and Cassidy 1997; Cassidy et al. 1997), slider (Cassidy et al. 1997) and painted turtle(Cassidy et al. 1997) and bullfrog (Cassidy et al. 1997) exist in and alongside the mainstem river in the Middle Green River subwatershed.

Bullfrogs were introduced into the Puget Sound lowlands in the 1930's from their native range in the eastern United States. Bullfrogs prey on juvenile salmon where they co-exist. Bullfrogs have been observed in the Green River Watershed and could potentially exist in ponds and off-channel habitats along the mainstem Green River, and could represent an important predator for native salmonids in the middle Green River.

PLANTS

Several non-native plants are common and widespread throughout King County and are likely to be present in the Middle Green River subwatershed.; however, the most highly invasive ANS prefer either lake or estuarine environments (WANSPC 1998). A variety of non-native herbaceous and shrubby plants that tend to form dense colonies are known to occur along the river, and may preclude the establishment of the natural riparian community. Species of particular concern include a variety of pasture grasses, reed canary grass (*Phalaris arundinacea*), Himalayan and evergreen blackberry (*Rubus discolor* and *R. laciniatus*), and Japanese knotweed (*Polygonum cuspidatum*).

LOWER GREEN RIVER SUBWATERSHED (RM 11 – RM 31)

FISH

Adult Atlantic salmon that have escaped from marine net pens are known to enter the Lower Green River (Tom Cropp 2000). Except for the rare stray (i.e., barracuda in the Duwamish River [Warner 200]), interviews with regional biologists indicate that there are no other known observations of non-native fish species in the lower mainstem Green River. However, because the Lower Green River subwatershed contains several lakes known to contain non-native warmwater species (Section 5.2.6), it is possible that these fish are sometimes able to access the tributaries and mainstem.

OTHER ANIMALS

Only a few non-native animals other than fish potentially occur in the Lower Green River Watershed. These species include livestock, nutria (Johnson and Cassidy 1997; Cassidy et al. 1997), bullfrog (Cassidy et al. 1997; McAllister 2000), slider turtle (Cassidy et al. 1997; McAllister 2000), painted turtle (Cassidy et al. 1997; McAllister 2000), snapping turtle (McAllister 2000), and spiny softshell turtle (McAllister 2000).

Both the snapping turtle and spiny softshell turtle are now found in Lake Washington (McAllister 2000). Although there is no documentation of sliders and painted turtles in WRIA 9, it is likely that they are present (McAllister 2000).

PLANTS

Several non-native plants are common and widespread throughout King County and are likely to be present in the Lower Green River subwatershed. A variety of non-native herbaceous and shrubby plants that tend to form dense colonies are known to occur along the river Species of particular concern include a variety of pasture grasses, reed canary grass (*Phalaris arundinacea*), Himalayan and evergreen blackberry (*Rubus discolor* and *R. laciniatus*), and Japanese knotweed (*Polygonum cuspidatum*). Two non-native plant species, blackberry and reed canarygrass, form a virtual biculture along the levees and revetments adjacent to the Lower Green River (Schaefer 2000).

GREEN/DUWAMISH ESTUARY

FISH

Adult Atlantic salmon that have escaped from marine net pens are known to occur in Elliott Bay and occasionally enter the Green/Duwamish Estuary, but there is no evidence that the species has propagated in the basin. With the exception of the occasional stray fish (e.g., barracuda), interviews with regional biologists indicate that there are no other known observations of non-native fish species in Elliott Bay or the Green/Duwamish Estuary (Cropp 2000; Geist 2000; Cordell 2000).

The potential freshwater non-natives discussed in previous sections would be limited to areas of the upper estuary. Warner and Fritz (1995) found fresh water at all depths and tides at RM 10.4, but salinities between 25 and 28 ppt were found at RM 7.5 at depths below 3 ft.

OTHER ANIMALS

Cordell (Cordell 2000) documented three non-native benthic invertebrates in the Green/Duwamish Estuary—the amphipod *Grandidierella japonica*, the tanaid *Sinelobus stanfordi*, and the cumacean *Nippoleucon hinumensis.* The Puget Sound Expedition, which documented non-indigenous marine invertebrate and plant species in all of Puget Sound, found 38 non-indigenous species in the sound as presented in Table 5.1.6-1. It is not known what proportion of these species were found in Elliott Bay. Non-native animals other than fish and invertebrates are not expected to occur in the Green/Duwamish Estuary or Elliott Bay area. The estuary and bay are highly developed and provide very little natural terrestrial or riparian habitat. The potential presence of nutria, bullfrog, and turtle species is diminished in the estuary because these species are common to freshwater habitats.

PLANTS

Several non-natives plant species are known to occur in the Green/Duwamish Estuary, including common reed (*Phragmites australis*), Himalayan blackberry (*Rubus discolor*), evergreen blackberry (*R. laciniatus*), Japanese knotweed (*Polygonum cuspidatum*), and reed canarygrass (*Phalaris arudinacea*). During a May 1999 field reconnaissance, Pentec Environmental found that blackberry shrubs (likely a mixture of *R. discolor* and *R. laciniatus*) were well established in the upper riparian zone of the estuary between RM 11.0 and RM 5.3. It is the most common shrub species present along the Duwamish River. Common reed has become well established in two locations in the Green/ Duwamish Estuary-Kellogg Island, located between RM 2.0 and RM 1.0, and the 509 marsh area located between RM 3.0 and RM 2.5. Other species of concern in the estuary include common tansy (*Tanacetum vulgare*), yellow iris (*Iris pseudacorus*), and Scots broom (*Cytisus scoparius*) (Dean 2000).

Table RIP-1. Non-native marine invertebrate and plant species found in Puget Sound by the 1998 Puget Sound Expedition.			
General Taxon	**Scientific Name**	**Native Range**	**First Puget Sound Record**
Seaweed	**Sargassum muticum**	Japan	1948
Seagrass	*Spartina anglica*	England	1961-1962
Seagrass	*Zostera japonica*	Japan	1974
Foraminifera	*Trochammina hadai*	Japan	1971
Cnidaria - Hydroid	*Cordylophora caspia*	Black Sea	ca. 1920
Cnidaria - Anemone	*Diadumene lineata*	Asia	< 1939
Annelida	*Hobsonia florida*	NW Atlantic	1940
Annelida	*Pseudopolydora paucibranchiata*	Japan	1993
Mollusca – snail	*Batillaria attranmentaria*	Japan	1924
Mollusca – snail	*Crepidula fornicata*	NW Atlantic	1905
Mollusca – snail	*Myosotella mysotis*	Europe?	1927
Mollusca – bivalve	*Crassostrea gigas*	Japan	1875
Mollusca – bivalve	*Mya arenaria*	NW Atlantic	1888-1889
Mollusca – bivalve	*Nuttallia obscurata*	Japan, Korea	1993
Mollusca – bivalve	*Ruditapes philippinarum*	NW Pacific	1924
Copepoda	*Choniostomatid copepod*	Unknown	1998
Cumacia	*Nippoluecon hinumensis*	Japan	mid-1990s
Isopoda	*Limnoria tripunctata*	Unknown	1962
Amphipoda	*Ampithoe valida*	NW Atlantic	1966
Amphipoda	*Caprella mutica*	Japan	1998
Amphipoda	*Corophium acherusicum*	N Atlantic	1974-1975
Amphipoda	*Corophium insidiosum*	N Atlantic	1949
Amphipoda	*Eochelidium* sp.	Japan or Korea	1997
Amphipoda	*Grandidierella japonica*	Japan	1977
Amphipoda	*Jassa marmorata*	NW Atlantic	1990?
Amphipoda	*Melita nitida*	NW Atlantic	1998
Amphipoda	*Parapleustes derzhavini*	W Pacific	1998
Entoprocta	*Barentsia benedeni*	Europe	1998
Bryozoa	*Bowerbanki gracilis*	NW Atlantic?	< 1953
Bryozoa	*Bugula* sp.	Unknown	1993
Bryozoa	*Bugula* sp.	Unknown	1998
Bryozoa	*Bugula stolonifera*	N Atlantic	1998
Bryozoa	*Cryptosula pallasiana*	N Atlantic	1998
Tunicata	*Botrylloides violaceus*	Japan	1973
Tunicata	*Botryllus schlosseri*	NE Atlantic	1970s
Tunicata	*Molgula manhattensis*	NW Atlantic	1998
Tunicata	*Ciona savignyi*	Japan	1998
Tunicata	*Styela clava*	China	1998

MAJOR TRIBUTARIES TO THE GREEN RIVER

SOOS CREEK

FISH

Soos Creek drains several lakes and tributaries that are known to contain non-native warmwater fish (Section 5.2.6). Informal observations of non-native fish at the Soos Creek Fish Hatchery include occasional bass, bluegill, and catfish [probably bullhead] (Wilson 2000). As mentioned previously, occasional Atlantic salmon have been captured and removed from hatchery's fish rack.

OTHER ANIMALS

Non-native animals other than fish that may be present in and along Soos Creeks include livestock, nutria (Johnson and Cassidy 1997; Cassidy et al. 1997), slider turtle (Cassidy et al. 1997), painted turtle (Cassidy et al. 1997), and bullfrog (Cassidy et al. 1997).

PLANTS

Several non-native plants are common and widespread throughout King County and are likely to be present in and along Soos Creeks. Where the banks along the stream have been modified by agriculture and other land uses dense stands of blackberry and reed canarygrass are common. Some sections of these streams are bordered by lawns that may include ornamental plants and pasture grasses.

NEWAUKUM CREEK

FISH

There are no documented observations of non-native fish in Newaukum Creek. However, it is likely that warmwater fish originating from upstream ponds and lakes are occasionally present in the stream.

OTHER ANIMALS

Non-native animals other than fish that may be present in and along Newaukum Creek include livestock, nutria (Johnson and Cassidy 1997; Cassidy et al. 1997), slider turtle (Cassidy et al. 1997), painted turtle (Cassidy et al. 1997), and bullfrog (Cassidy et al. 1997).

PLANTS

Several non-native plants are common and widespread throughout King County and are likely to be present in and along Newaukum creeks. Where the banks along the stream have been modified by agriculture and other land uses, dense stands of blackberry and reed canarygrass are common. Some sections of these streams are bordered by lawns that may contain ornamental plants and pasture grasses.

LIST OF TABLES

Table RIP-1: Non-native marine invertebrate and plant species found in Puget Sound by the 1998 Puget Sound Expedition.

Habitat Limiting Factors and Reconnaissance Assessment Report

Green/Duwamish and Central Puget Sound Watersheds

(Water Resource Inventory Area 9 and Vashon Island)

Volume II

December 2000

KING COUNTY

Washington State Conservation Commission

PART II: FACTORS OF DECLINE/CONDITIONS

3. Tributary Conditions

3.1 Longfellow Creek Subbasin

3.2 Hamm Creek Subbasin

3.3 Springbrook Creek Subbasin

3.4 Mill Creek & Mullen Slough Subbasin

3.5 East Hill Tributaries of the lower green river

3.6 Middle Green River Tributaries

3.7 Soos Creek Subbasin

3.8 Newaukum Creek Subbasin

3.9 Coal and Deep Creeks Subbasins

3.10 Upper Green River and Sunday Creek Watershed Administrative Unit

3:11 Lester Watershed Administrative Unit

3.12 Independent Nearshore Tributaries in WRIA 9

3.13 Vashon and Maury Islands Subbasin

3. TRIBUTARY CONDITIONS

SALMONID HABITATS IN THE TRIBUTARIES OF THE GREEN/DUWAMISH RIVER BASIN, WRIA 9 DIRECT DRAINAGES TO PUGET SOUND AND VASHON ISLAND

GENERAL OVERVIEW

Many of the tributaries of the Green/Duwamish River are among some of the most hydrologically altered streams in the Puget Sound ecoregion. The tributaries of the lower Green/Duwamish River exist in heavily urbanized locale and are subjected to the adverse habitat impacts that accompany this setting. These streams and their subbasins generally have high levels of impervious surfaces, altered hydrologic regimes, loss of floodplain connectivity, poor riparian conditions and water quality problems. As one moves upstream into the middle reaches of the watershed, the habitat conditions of the tributary streams show some improvement and the land use becomes a mix of residential, agricultural and forestry. Tributaries in the middle reach still do not meet many of the criteria necessary for properly functioning habitats important for salmonid survival. Upstream of the Tacoma Headworks Dam, the tributary streams are almost exclusively in lands utilized for commercial forestry and recreation. While the habitat around these streams is generally better than downstream, it has problems typically associated with commercial forestry and damage to habitat forming processes are less permanent.

In this chapter, the tributaries of the Green/Duwamish watershed (WRIA 9) and Vashon Island (a portion of WRIA 15) are subdivided into important streams as follows:

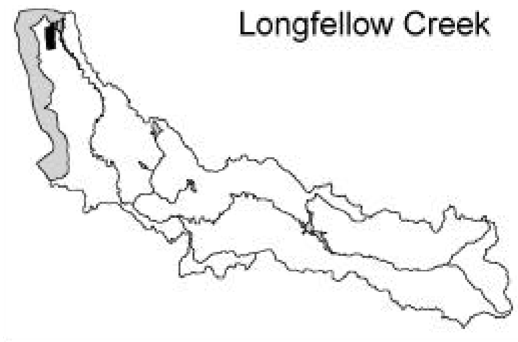
- Longfellow Creek Subbasin (chapter 3.1);
- Hamm Creek Subbasin (chapter 3.2);
- Spring Brook Creek Subbasin (chapter 3.3);
- Mill Creek and Mullen Slough Subbasin (chapter 3.4);
- East Hill Tributaries Subbasin (chapter 3.5);
- Middle Green River Tributaries Subbasin (chapter 3.6);
- Soos Creek Subbasin (chapter 3.7);
- Newaukum Creek Subbasin (chapter 3.8);
- Coal and Deep Creek(s) Subbasin (chapter 3.9);
- Upper Green River and Sunday Creek Subbasin (chapter 3.10);
- Lester WAU Subbasin (3.11)
- Puget Sound Creeks (chapter 3.12); and
- Vashon and Maury Island Creeks (chapter 3.13).

There are numerous additional tributary streams not covered in this assessment. Generally these streams do not have anadromous fish access or have very limited amounts of access. However, the absence of these creeks in this report should not be interpreted as diminishing their importance, rather the lack of information that was located during the course of this investigation.

3.1 LONGFELLOW CREEK SUBBASIN (09.0359)

Physical Description 2
  Subbasin 2
  Stream Course and Morphology 2
  Salmonid Use 3
Factors of Decline 4
  Fish Passage 4
  Land Use 4
  Riparian Condition 5
  Hydrology 7
  Hydromodification 8
  Water Quality 9
  Sediment Condition 11
  Non-Native Species 11
Key Findings and Identified Habitat-limiting Factors 12
Data Gaps 12
Recommended Early Actions 13

3.1. LONGFELLOW CREEK SUBBASIN (09.0359)



PHYSICAL DESCRIPTION

SUBBASIN

The basin is comprised of one distinct physical setting that was defined by the retreat of glaciers about 13,500 years ago. This retreat left a series of physical features that were shaped by the grinding action, which today are best described as depressions or hollows.

The Longfellow Creek Subbasin, is located in West Seattle's Delridge and Westwood Neighborhoods, entirely within the boundaries of the City of Seattle. Because the subbasin lies within a heavily urbanized area the borders are best defined geographically by using street names. Longfellow Creek subbasin is that area between SW Roxbury Street at the Seattle City limits to the south; between 13th Avenue SW and 21st Avenue SW on the east; 35th Avenue SW on the west (with an extension out to 41st Avenue SW in the northern portion of the subbasin); and north to SW Spokane Street and the industrialized area under the West Seattle Freeway to the north. Generally flowing from the south to the north, Longfellow Creek does not flow directly into the Duwamish River but rather into the West Waterway (also referred to as the West Duwamish Waterway. Longfellow Creek appears to fall under the category of "tributary to the Duwamish River" as defined by the boundaries used for the Duwamish River in 173-201A WAC, WQ Standards for surface waters in WA).

STREAM COURSE AND MORPHOLOGY

Longfellow Creek flows from an area of approximately 2,685 acres and was calculated as approximately 1.45 miles in length (Williams 1975) and more recently 4.2 miles long (J. Starstead, pers comm.).

The historical headwaters are located at a natural wetland and peat bog in what today is Roxhill Park. Even today, portions of Roxhill Park have been reported to be so wet that they are unusable for recreational activities. Seattle Parks is currently undertaking a project to reestablish this historic headwaters site through daylighting of the creek (which is now in a stormdrain beneath the site) and re-creation of the peat-based bog (which was filled many years ago). This project has the potential for improving water quality and stabilizing flows entering Longfellow Creek at its historic headwaters. After leaving Roxhill Park, the creek travels north in pipes beneath the Westwood Village Shopping Center, which when constructed, was built on driven piles due to unstable soils. The upper 4,900 feet of Longfellow Creek is fully contained in pipes of various sizes. Today, approximately one third of the creek length lies within enclosed pipes and travels under developed urban areas including shopping centers, houses and roads.

The creek initially appears above ground at a Seattle Department of Parks and Recreation (Parks) open space site in the vicinity of 24th and 25th Avenues Southwest and north of Southwest Thistle Street. After leaving this location, the creek meanders through multi-family residential property before entering the 5-acre SW Webster Street Water Detention facility. This detention facility was recently modified in 1999, to improve operational efficiency during small and large storms and improve wetland habitat inside the facility. The creek exits the detention facility through a 60-inch by-pass pipe that runs along the back of K-Mart and reconnects with open channel at SW Myrtle Street.

Longfellow Creek meanders a considerable distance between private property, the West Seattle Golf Course, and a four-block Seattle Parks open space site, prior to entering a pipe at Southwest Andover Street and traveling beneath yet another parking lot. In the vicinity of Southwest Spokane Street, the Longfellow Creek pipe connects with another pipe carrying stormwater and the combined flow discharges into the West Duwamish Waterway.

Longfellow Creek has two small, unnamed tributaries, both of which were not identified in Williams (1975). Both tributaries are on the left bank and the largest is located in the West Seattle Golf Course. The tributaries are believed to be too small for anadromous fish use, but the lower reaches, particularly of the tributary in the golf course, may be important refugia for overwintering salmonids from high flows (MacIntosh, 1990).

Information concerning the amount of total effective impervious surfaces within this basin was not located during the course of this investigation. However, given the heavy urbanization and residential development it is assumed to be quite high.

SALMONID USE

The known freshwater distribution of anadromous salmonids and the presumed distribution of coho and steelhead are depicted in the report Appendix. This presumed distribution uses a stream gradient of $\geq$12 percent as the point which steelhead and coho are presumed to be present. Historically, Longfellow Creek was thought to contain populations of coho salmon, cutthroat trout and steelhead trout (MacIntosh 1990). Williams (1975) indicated that the stream might contain coho salmon. The WDFW Spawning Ground Survey Database (1999) does not contain any indication of adult salmonid observations in Longfellow Creek for any species. Prior to the middle 1990’s there was the rare report of an adult salmonid observed (Dick Lunt, 1990, personal communication reported to B. MacIntosh) and the creek was not believed to support a self-sustaining population of any salmonid species.

MacIntosh (1990) observed coho smolts and juvenile coho rearing in portions of Longfellow Creek. In 1999, Seattle Public Utilities (SPU) conducted spawning surveys on Longfellow Creek. These surveys indicated the presence of sixty (60) adult coho salmon. During 1998, SPU staff observed forty-four (44) adult coho salmon carcasses stranded along the banks of lower Longfellow Creek. *The Riparian Zone*, a local citizen newsletter about events of Longfellow Creek basin, also reported adult salmon sightings by local neighbors in both the Fall of 1995 (approximately 20 coho), and reported anecdotal accounts from December 1993 and 1994, of 13, and 2 adult coho, respectively.

In addition, juvenile rainbow trout and coho salmon were captured during electrofishing surveys in 1999, from the mouth up to SW Graham, and up to SW Oregon streets, respectively (Washington Trout, In Preparation). It is not known if the creek supports a self-sustaining population of coho salmon, because it is not known if the adult coho returning to the creek originate from hatchery strays, hatchery releases, or are being produced by the system (Katherine Lynch, pers. comm.).

Numerous groups have released coho salmon fry into Longfellow Creek for several years. Coho smolts and juvenile coho have been observed rearing in portions of Longfellow Creek (MacIntosh 1990; Washington Trout, In Preparation). To date there have not been any verifiable adult salmonid returns linked to these programs due to lack of a monitoring program.

FACTORS OF DECLINE

FISH PASSAGE

There are several known and potential barriers in this system. Some are located in pipelines, such as the lower 3,161 feet, and likely occur when maintenance has not removed debris. A list of known and potential culverts is shown in table LONG 1.

LONG 1: Longfellow Creek Known and Potential Barriers to Anadromous Salmonids			
Location	**Known**	**Potential**	**Brief Description**
Downstream of Andover St.		X	Debris in pipe could be a barrier
Culvert under Genesee St.		X	Culvert with a 45 degree bend
Culvert under 12th Fairway, W. Seattle Golf Course		X	Long, narrow culvert with 2.5 percent gradient
Golf Course falls	X		Constructed waterfall, cats as upper limit for anadromous fish
South end of W. Seattle Golf Course	X		Perched (2') culvert
Culverts at Willow Street	X		Perched culverts 3-4 feet above streambed.
Culvert under K-Mart parking lot	X		Velocity barrier and may represent upper limit accessible to fish
Miscellaneous debris barriers	X	X	Require annual maintenance through streamwalks.

LAND USE

The percent of impervious surfaces in the Longfellow Creek subbasin are approximately 45 percent in the upper part of the basin, 35 percent in the middle part of the basin, 50 percent in the lower part of the basin (Longfellow Creek Watershed Characterization Background Report, 1992).

RIPARIAN CONDITION

MacIntosh (1990) examined the riparian habitat of Longfellow Creek as a part of the Puget Sound River Basin Team. She divided the creek into segments, working from downstream to upstream, and provided narrative descriptions of each segment. These same segments were used as a basis for a habitat evaluation in the Longfellow Creek Habitat Restoration Master Plan, January 1999. The information below is attributed to MacIntosh et al unless otherwise noted.

Segment 1. The lower 3,161 feet is completely contained within a culvert. The Port of Seattle installed "skylights" in 1998, in an attempt to improve fish passage and has committed to outfall and pipe hydraulics improvements at some time in the future. There has not been any monitoring program in place to determine the effectiveness of these "skylights". Because this stream segment is entirely within pipes there is no effective riparian habitat. Land use within this reach is predominantly scattered residential and industrial.

Segment 2. This segment lies between the culvert intake at Andover Street and Genessee Street. The four-block open space between SW Yancy and SW Genesee Streets has been purchased as Seattle Parks open space. Land use within this reach is predominantly scattered residential and industrial. This segment ranked as a high priority in the Master Plan, based on minimal obstacles to salmon; reasonable habitat potential; and, high public visibility and accessibility.

There is no quantifiable data for canopy coverage or age but the riparian habitat was considered "fair to good" in the lower portions of this reach and "lacking" in the upper portions. There were several unvegetated eroding stream banks observed in this reach in 1990. Site restoration work is currently underway here, and instream and upland improvements are scheduled for completion in 2001.

Segment 3. The majority of this reach is located within a wooded ravine in the West Seattle golf course, and includes that portion of open channel from SW Genesee Street to the confluence of unnamed tributary in golf course. Two major obstructions prevent salmon access to relatively good habitat upstream. Public access is now limited. In the lower portions of this reach there is some canopy present but it is generally considered "lacking". Upstream of the lower 150 feet the canopy quality improves. Golfers searching for "missing" golf balls have cut numerous trails into the riparian corridor and contribute to its degradation.

Segment 4. This segment consists of a small left bank tributary that drains from a steep ravine believed to originate from a brushy wetland area to the west. Numerous small slides have occurred in the upper portion of the tributary channel. This area probably accounts for a significant proportion of the observed suspended sediment load in the main channel. Here too, golfers searching for "missing" golf balls have cut numerous trails into the riparian corridor and contribute to its degradation.

Segment 5. This reach extends from the confluence of the left bank tributary upstream to SW Brandon Street and winds through a wooded ravine. The overhead canopy was considered "dense" except in the vicinity of the several golf course walkways across the creek. Recurrent bank failure problems exist in this reach and one channel obstruction is present.

Segment 6. This reach extends from SW Brandon Street upstream to the location of the stormwater bypass segment enters the mainstem of Longfellow Creek. Numerous trails and pathways have effectively eliminated much of the riparian vegetative zone. The overhead canopy was termed “dense”. The upper portions of this reach have a riparian zone termed “brushy” with only minimal overhead canopy present.

Segment 6. This reach extends from SW Brandon Street upstream to the outlet of the stormwater bypass channel north of SW Findlay Street. MacIntosh indicated that numerous trails and pathways have effectively eliminated much of the riparian vegetative zone. The overhead canopy is termed “dense”. The upper portions of this reach have a riparian zone termed “brushy” with only minimal overhead canopy present.

Segment 7. This reach includes open channel from the bypass channel outlet to SW Juneau Street (bypass channel starts at SW Juneau Street). The reach is characterized by a highly modified stream bank that has been channelized and armored, and flanked on both sides by private property. . A corresponding amount of limited canopy and overhanging vegetation is present.

Segment 8. This reach stretches from SW Juneau Street upstream to SW Graham Street and has a “dense” canopy present throughout most of its length. There are local areas where no canopy is present. Himalayan blackberries and reed-canary grass are present in areas with minimal or no canopy.

Segment 9. This reach extends between SW Graham Street to SW Willow Street and flows primarily through a residential area in the lower portion and a park-like area in the upper section. Canopy was termed “adequate” in the upper section.

Segment 10. Flowing between SW Willow Street and SW Myrtle Street, this section had stream associated vegetation that was dense and brushy.

Segment 11. This segment is comprised of a piped channel from SW Myrtle Street to the SW Webster Street Detention Basin, and an open channel from the detention basin to SW Holden Street. Most of the segment is piped, with modest trout habitat potential within the open channel portion. Rock grade control structures located in the stream channel upstream of the detention basin are two feet high, and impede passage by all anadromous and resident fish species. Seeps from hillside behind K-Mart may contribute fine sediments to bypass pipe. Streambank erosion was observed along channel upstream of the detention basin.

Segment 12. This reach extends between SW Holden and SW Thistle Streets, and contains modest trout habitat potential. Most of the segment is on private land, with the exception of a small open space parcel, contiguous with Chief Sealth High School. The creek is highly visible to local apartment dwellers, and there is little to no riparian buffer in this reach as high-density housing is constructed in some cases to the stream’s edge. Open space next to high school has been recently improved with trails and native vegetation in recognition that this “headwater” reach is important to downstream segments.

In conclusion, the riparian habitat of Longfellow Creek suffers from many of the ailments associated with urbanization including in many reaches dominated by non-native plant species, lack of suitable buffer width or functioning buffer and can only be considered to be "Not Properly Functioning."

LARGE WOODY DEBRIS

There has been no quantification of LWD in Longfellow Creek, but visual stream surveys by MacIntosh (1990) indicate that LWD is quite limited. This is probably due to inadequate recruitment potential from the degraded riparian zone.

MacIntosh (1990) specifically noted the need for additional instream structure and wood placement. Seattle Public Utilities began adding LWD to Longfellow Creek in 1999, particularly to the stream reach between Andover and Genesee streets, where most of the adult coho were recorded during spawning surveys in 1999 (WA Trout, In Preparation). Although LWD is limiting in Longfellow Creek, it has been placed in critical reaches over the last couple of years, and may not be a major limiting factor compared to stormwater runoff. Specific stream channel and riparian improvement projects identified by the Longfellow Creek Master Plan are intended to improve fish passage and access to significant habitat areas, and enhance available salmonid habitat via a combination of in-stream and riparian habitat diversity and channel stabilization

HYDROLOGY

MacIntosh (1990) suggested that the high quantity and degraded quality of stormwater was detrimental to salmonid production. Davis et al (1992) also concluded that the adverse effects of increased volumes of stormwater flows and decreased volumes of low flows were a result of urbanization in the subbasin. The Longfellow Creek Wastewater Management Committee identified the issues associated with high stormwater flows and increased urban runoff as principle problems facing the creek (Davis 1992a).

This problem persists, at least in part, due to the City of Seattle Comprehensive Drainage Plan adopted in 1989 that states that Longfellow Creek will remain the principle conduit for stormwater for the drainage basin. One solution to this problem is to control the flow rate and treatment of stormwater to the creek.

Very few flow measurements have been taken in Longfellow Creek, and no hydrograph has been established for the creek. Flow was measured in 1976 at 2.5 cubic feet per second (cfs) at SW Webster Street and SW Andover (City of Seattle 1977). Flow measurements taken in 1990 at SW Adams Street averaged 1.15 cfs (Davis et al. 1990). It is unclear if the dates of both measurements were similar, but both were attributed to possible low flow measurements. It is believed that impervious surfaces increased in the intervening 14 years. Increases in impervious surfaces results in less infiltration and are associated with a decrease in low flows, and an increase in the magnitude, duration, and frequency of storm events (Booth, 1991).

Longfellow Creek is the natural drainage conveyance for a watershed of approximately 2,685 acres. Today, Longfellow Creek receives surface water from natural areas in addition to stormwater runoff from streets, paved areas such as parking lots, and run-off from a series of constructed ditches. Some of these ditches are lined with impervious materials while others have placed rocks or vegetation. Collectively, these all channel stormwater into Longfellow Creek.

Approximately 45 percent (1,208 acres) of the subbasin is served by combined sewers. The remainder collects surface water in ditches and pipes and delivers it directly to the creek. Sewers and storm drains were separated along SW Roxbury, SW Webster, and through most of the lower watershed by the late 1970's. Drainage improvements in the early 1980's included: separation of sewers and storm drains, the construction of a 26-acre foot capacity detention basin at SW Webster Street, and installation of four combined sewer overflow holding tanks (10 yr-storm event capacity). A by-pass was constructed between SW Juneau and SW Findlay in 1989 to relieve a channel constriction and associated flooding.

HYDROMODIFICATION

Longfellow Creek, as is the case with many streams in urbanized settings, has undergone a long history of extensive floodplain modifications. The City of Seattle calculates the length of Longfellow Creek as 20,630 feet long (Joe Starstead, pers. comm., calculated from GIS measurements) and with two left bank unnamed tributaries each contributing approximately 1,300 and 270 additional linear feet there is approximately 22,200 total linear feet of creek length (Joe Starstead, SPU, personal communication, calculated from GIS measurements). Approximately 8,200 (36.1%) linear feet of Longfellow Creek lie entirely within pipelines and another 1,034 (4.7%) linear feet under road crossings (Joe Starstead, SPU, pers. comm., calculated from GIS measurements). There are also numerous sections that are channelized, between bank hardening features such as rock gabions, poured concrete walls, large placed rocks and stacked broken slabs of concrete. The channelization of this creek has caused a simplification of channel complexity, increased water velocities, loss of pools for juvenile rearing and adult and juvenile holding, loss of spawning habitat, loss of side channels, loss of any significant wood recruitment and loss of connectivity with its historic floodplain.

The length of these areas was not available for this report but based on professional observations (MacIntosh 1990) it is expected to be significant.

While there has not been an exhaustive inventory of floodplain modifications there is sufficient data (MacIntosh 1990, Davis 1992a, Davis 1992b) to indicate extensive modifications have occurred". MacIntosh (1990) did conclude that despite urbanization, the subbasin still contained some usable fish habitat. This information, in combination with the presence of juvenile rainbow and coho found during the1999 electrofishing surveys (WA Trout, In Preparation, Taylor & Associates, 1999) suggests that there are reaches within Longfellow Creek that possess some capacity to support juvenile salmonid rearing. However because of the extensive amount and nature of the modifications to the floodplain it should be rated as severely impaired and "Not Properly Functioning."

OFF CHANNEL HABITAT

The ability of Longfellow Creek to form off-channel habitats has been eliminated in approximately the 40 percent of the creek where it is within pipelines. Other portions of Longfellow Creek are channelized between bank hardening structures that limit lateral movement that is necessary to form many off-channel habitats.

FLOODPLAIN CONNECTIVITY

The extent and form of channelization within Longfellow Creek has greatly interfered with this system's capacity to connect to its historic floodplain. Additionally, as in many urban streams, increases in streamflow have caused the creek to incise in many places, further impacting floodplain connectivity.

WATER QUALITY

Longfellow Creek is designated as a Class A stream by WDFW and WDOE. While Longfellow Creek does not directly flow into the Duwamish-Green River, it is considered a tributary to the Duwamish River, which is designated as a Class B surface water (Chapter 173-201A WAC). However, water quality is only currently listed as degraded for fecal coliform violations on the EPA 303(d) list for 1998. Table LONG 2 illustrates the Environmental Protection Agency 303(d) 1998 list for Longfellow Creek.

LONG 2: Environmental Protection Agency, Clean Water Act 303(d) 1998 List for Longfellow Creek

Sampling Location (RM)	Parameter
LFC 24	Fecal Coliforms
RM 1.1	Fecal Coliforms
RM 0.5	Fecal Coliforms
LFC 1	Fecal Coliforms
LFC 3	Fecal Coliforms

While fecal coliform violations are a human health threat, they are not necessarily a threat to natural salmonid life history stages. However, they may be an indicator of overall stream health and because of the multiple excursions beyond acceptable limits provide cause for concern. Fecal coliform counts were noted to exceed acceptable limits when samples were taken during both low flows and storm events (Goldberg et al 1992, Minton 1998). They also noted increased levels of Total Suspended Solids (TSS) and turbidity during storm events and metal concentrations increased as TSS increased.

A more suitable indicator of overall stream health is the presence, diversity and population of benthic invertebrates. MacIntosh (1990) and Goldberg (1992) both indicate an overall lack of benthic invertebrates that is indicative of overall stream degradation. Healthy populations and species diversity of aquatic invertebrates have not been found in Longfellow Creek (Davis et al 1992, Goldberg 1992). This may be due to a combination of factors including high storm flows, low base flows, degraded water quality and/or degraded habitat conditions.

During water quality sampling conducted prior to 1992, Longfellow Creek exceeded state water quality criteria for fecal coliforms, turbidity, lead, copper, zinc and dissolved oxygen. The levels of total lead, copper, and zinc exceeded both acute and chronic criteria more than 50 percent of the time during storm flows but not during low flows.

Longfellow Creek Data Review and Segment Ranking Technical Memorandum, September 1998, reviewed the water quality data contained in the *Longfellow Creek Background Characterization Report* (City of Seattle 1992) and in the draft *Review of Water and Sediment*

Quality Data for Longfellow Creek (Resource Planning Associates 1998). In addition, this technical memorandum reviewed water quality data provided by Seattle Public Utilities (SPU). The monitoring data provided by SPU are summarized in LONG 3 below.

LONG 3: Longfellow Creek Water Quality Sampling Locations

Station ID	Location	Sampling Period	No. of Baseflow Samples[1]	No. of Storm Samples[1]
C370	Longfellow Creek at Yancy Street	3/93-12/97	46	11
LFC3	Longfellow Creek at Adams Street	11/79-7/90	49	12
LFCP23	Storm drain pipe discharging to Longfellow Creek near Edmunds Street	3/90-7/90	0	6
J370	Longfellow Creek at Brandon Street	12/92-12/97	46	12
LFC24	Longfellow Creek at Findlay Street	11/87-6/90	2	19
LFCP25	Storm drain pipe discharging to Longfellow Creek near Myrtle Street	3/90-7/90	2	13
Sta91	Longfellow Creek at Graham Street	12/95-4/97	0	8
LFC1	Longfellow Creek upstream of Webster Basin	5/89-7/90	5	8

Note: Baseflow and storm samples identified in *Review of Water and Sediment Quality Data for Longfellow Creek* (Resource Planning Associates 1998).

Evaluation of this data was confined to sampling results collected since January 1990. Key findings, related to descriptive statistics (e.g., median, mean, maximum, minimum) for each constituent of potential concern, and compared with current state water quality criteria for Class A waters, are summarized as follows:

- Fecal coliform densities often exceeded the state criteria during storm events. Fecal coliform is a human health concern but not a major aquatic life concern. Domestic pets and geese are believed to be the most likely sources of fecal coliform in stormwater runoff. Combined sewer overflow at SW Henderson Street and SW Orchard Street are also potential sources. Fecal coliform densities were occasionally high in baseflow samples, which may indicate leaking sanitary lines or cross-connections to the storm drain system.

- Overall water quality was fair for aquatic life. Under baseflow conditions, the creek generally met the water quality criteria for aquatic life protection. However, samples collected during storm runoff occasionally exceeded the criteria for copper, pH, and temperature.

- Dissolved oxygen (DO) did not meet the state criteria on two occasions. However, DO has not been measured at night or just prior to first light, when aquatic plant respiration tends to reduce DO levels. Water temperature exceeded the state criteria on a few occasions during the months of July and August.

- Total suspended solids and turbidity were often elevated during storm events.

- Nitrate-nitrogen was often elevated. Total phosphorus concentrations were within the typical range for urban streams. The lack of DO problems suggests that nutrient enrichment has not had a major impact on the creek.

- Samples collected from the two storm pipelines generally contained higher pollutant concentrations than the in-stream stations.

- There was little difference in water quality among the creek stations. Water quality in the upper, middle, and lower reaches was similar. This spatial pattern indicates that there are no major point sources (or distinct non-point source areas) affecting the creek between monitoring stations.

Table 4-5 in the Longfellow Creek Data Review and Segment Ranking Technical Memorandum, summarizes the results of the water quality evaluation for each segment. Potential areas within each segment are noted in the table. (Attach).

SEDIMENT CONDITION

MacIntosh (1990) noted numerous areas where the streambed was sand, mud and/or compacted gravels. Some of these reaches were in areas that were on top of gabion bottoms. Rock gabions and/or cyclone fencing have been placed over the stream banks and streambed between Nevada and Genesee streets, which would limit access to spawning gravels in this reach (MacIntosh, 1990, WA Trout, In Preparation). High amounts of fine sediments were also present in several reaches.

Eroding stream banks were noted throughout the creek by MacIntosh (1990) and are one source of the sediment problems noted previously.

Although not surveyed, the apparent limited availability of suitable amounts and quality of spawning gravels may be a limiting factor to the natural production of salmonids in this stream. Erosion of streambanks and fine sediment input by stormwater contributes to the poor quality of those gravels that are present.

NON-NATIVE SPECIES

ANIMALS

No information was obtained to indicate the presence of non-native aquatic animal species.

PLANTS

Non-native plant species found in the subbasin include numerous ornamental species associated with plantings by private and public landowners. Examples include mountain ash (*Sorbus spp.*), blue beech (*Carpinus spp.*), butterfly bush (*Buddleia spp.*), cherry laurel *Laurocreasus officenalis*), dogwoods (*Cornus spp.*), and non-native rhododendrons (*Rhododendron spp*.). Exotic species of plants more closely associated with riparian and aquatic environments include: scotch broom (*Cytisus scoparius*), reed canarygrass (*Phalaris arundinacea*) which is abundant throughout this subbasin and Himalayan blackberry.

Non-native animal and/or plant species do not appear to currently be a limiting factor to natural salmonid production.

KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- Naturally producing anadromous salmonids may be absent from this subbasin, possibly since 1939. In recent years adult coho have been observed and recent electrofishing surveys indicate the presence of rainbow trout.
- The creek suffers from extensive channelization
- Water quality in Longfellow Creek is a significant adverse issue impacting anadromous fish success.
- Hydrologic regime has been severely altered along with system's ability to support salmonids
- Instream structures are needed to produce channel complexity for successful salmonid production.
- Known and potential anthropogenic barriers limit access to spawning and rearing habitat.
- The quality and quantity of gravels in the stream may be limiting anadromous and resident salmonid spawning success and potentially juvenile rearing.
- Although no quantifiable storm-flow information was available, it was the professional judgement of the TAG that flood flows due to increased impervious surfaces would serve to adversely limit any successful egg incubation.
- There are only limited amounts of off-channel habitat suitable for juvenile salmonid rearing and holding.

DATA GAPS

- Fish passage barriers have not been comprehensively assessed for the subbasin.
- Information regarding existing riparian conditions and functions for supporting salmon habitat is limited.
- There is no LWD inventory for the subbasin..
- Aquatic invertebrate populations should be monitored and the cause of lack of diversity and presence should be determined and addressed.
- Present fish use information of the system is not comprehensive.

- The state of the stream channel condition is unknown.

- Flow data is scarce or non-existent. Hydrologic analysis designed to assess the potential for salmon restoration is essential.

- The impacts of water quality to salmonid productivity have not been documented.

RECOMMENDED EARLY ACTIONS

- A comprehensive baseline habitat survey including elements that address the above referenced data gaps should be initiated to shape a subbasin-wide, ecosystem-based, stream rehabilitation strategy. The strategy should be used to direct the type and timing of rehabilitation activities to maximize resource potential and promote efficient expenditures.

LIST OF TABLES

Table LONG -1: Longfellow Creek Known and Potential Barriers to Anadromous Salmonids

Table LONG 2: Environmental Protection Agency, Clean Water Act 303(d) 1998 List for Longfellow Creek

Table LONG 3: Longfellow Creek Water Quality Sampling Locations

3.2 HAMM CREEK SUBBASIN

Physical Description 2
Subbasin 2
Stream Course Morphology 2
Salmonid Use 2
Factors of Decline 3
Fish Passage 3
Riparian Condition 3
Hydrology 4
Sediment Condition 5
Water Quality 5
Land Use 5
Non-Native Species 6
Hydromodification 6
Key Findings and Identified Habitat-limiting Factors 7
Data Gaps 7
Early Action Recommendations 7

3.2 HAMM CREEK SUBBASIN

PHYSICAL DESCRIPTION

SUBBASIN

Located immediately south of the Seattle City limits, locally named Hamm Creek (09.0002) is a small left-bank tributary to the Duwamish River. Draining an area of approximately 1,408 acres, the Hamm Creek subbasin is composed of four unofficially named perennial tributaries:

- South Fork;
- Middle Fork,
- Lost Fork; and
- North Fork.

STREAM COURSE MORPHOLOGY

The North, South and Middle Forks have their origins from a diverse series of groundwater seeps and springs that surface in roadside ditches in the hills west of the Duwamish River. These then drop through ravines along the western bluff line of the Duwamish River onto the valley floor. Historically, the lands downstream of this point were thought to have been a series of wetlands with largely undefined stream channels that connected to the Duwamish River.

The Middle Fork and North Fork join near S. 96th Street west of State Highway 99. When flows in these forks exceed the five-year interval storm event, they overflow into the Lost Fork. The Lost Fork originates from a diverse series of seeps and springs on the valley floor. The South Fork joins the combined three forks via a culvert at S. 95th Street. Hamm Creek then flows about 200 feet to the confluence with the Duwamish River at RM 4.95.

SALMONID USE

The known freshwater distribution of anadromous salmonids is depicted in the report Appendix. Hamm Creek historically was believed to contain populations of coho salmon, cutthroat trout and steelhead trout.

Currently, only the South Fork is thought to contain significant numbers of anadromous salmonids. At least one salmonid was reported observed in the spring-fed area of 96th Street ditch that is connected to the South Fork via culvert under Highway 99 (Tom Nelson, pers. comm.). During July, 2000, 322 cutthroat trout juveniles and 222 coho juveniles were estimated to have been removed from an approximately 400-meter reach in the area of construction downstream of Highway 99 near RM 0.3 (D. Eastman 2000, King County unpublished summary of Hamm Creek fish removal). Coho adults have been observed spawning in the South Fork up to RM 0.7. Coho and cutthroat juveniles were captured during 1998 project fish relocation near RM 0.5 and observed up to RM 1.0 (Tom Nelson, pers. comm.) Coastal cutthroat have been located in the upper reaches of Middle and North Forks and throughout the upper and lower reaches of the South Fork.

Some marginal salmonid habitat potential exists in the upper reaches of the North, Middle and South Forks above the valley floor.

FACTORS OF DECLINE

FISH PASSAGE

Fish passage into the Middle, North and Lost forks is partially obstructed at the perched outfall into the Duwamish River. The outfall is located within a reach of the Duwamish River that is subject to tidal influence, and adult and juvenile salmonids can only enter the system when the tide reaches approximately +6.5 feet (Cagney pers. comm.). The lower 190 feet of this stream is fully contained in a 6-foot-diameter pipe, which may also inhibit salmonid migration. While the gradient is relatively flat (approximately 1 percent), the lack of suitable holding areas and darkness may inhibit some upstream salmonid migration.

The South Fork converges with the other three forks via a 6-foot corrugated culvert. This culvert is integrated into the toe of a riprapped bank within the Duwamish Yacht Club boat basin. It is perched above the river at low tides.

A fish and wildlife restoration project was completed on the South Fork in 2000. A root complex forming at the channel nick point at RM .7 was creating a migration barrier in 1997 (Nelson, 1997).A new, fish-friendly outlet to the Duwamish River was constructed that should allow unrestricted salmonid access.

RIPARIAN CONDITION

The lower 190 feet of the South, Middle, North and Lost Forks is encased within a 190-foot-long, 6-foot-diameter pipe. Moving upstream, the pipe opens into a 60-foot-long stream reach of channel that is between buildings and paved surfaces. This channel has a less than 1 percent gradient, is roughly 8 feet deep, and has a bank width of 10 feet.

At approximately RM 0.1 the combined Middle, North and Lost Forks are again within a culvert until they reach the State Route (SR) 99 cloverleaf. It then emerges into a 225-foot-long trapezoidal channel where riparian vegetation consists of deciduous trees, Himalayan blackberry, reed canarygrass and nightshade. Upstream of the SR 99 cloverleaf, the creek traverses through a 50-foot-long open channel before it enters a 450-foot-long straight channel lined with Himalayan blackberries. At the upper end of this reach the creek enters a 1,010-foot-long culvert until it reaches the confluence of the North and Middle Forks.

The North Fork is completely encased in a culvert that is approximately 2,175 feet long that emerges in the vicinity of the west side of SR 509. At this point the North Fork ascends a steep ravine with riparian habitat consisting of immature deciduous trees, Himalayan blackberry, stink and red current.

The Middle Fork, upstream from the confluence with the North Fork, is encased within a 825-foot-long culvert. It then emerges in a reed- and canarygrass-lined 300-foot-long ditch that is fed by surface drainage through smaller culverts from the Rasmussen Wire Rope facility. Upstream of this point, the stream travels alternatively through reed- canarygrass-lined roadside ditches and culverts until it ascends the bluff via a 750-foot-long ravine where riparian habitat consists of deciduous trees and Himalayan blackberries.

The area of the South Fork enhancement project from Highway 99 to the Duwamish (RM 0.0 -0.5) will be revegetated with a variety of native plants including fresh and salt water emergents, shrubs and trees. In the Point Rediscovery reach (about RM 0.5 to 0.6), the adjacent stream corridor is dominated by red alder and Himalayan blackberry with some big leaf maple, recent small red cedar plantings, indian plum, horsetails, snowberry and ivy. Upstream of Des Moines Way at RM 0.6 to RM 0.7, the one- to two-percent-gradient stream enters a 600-foot-wide ravine. The ravine provides a good vegetative buffer from the top-of-slope residential development. Large deciduous trees (big leaf maple, alder and cottonwood) with some sporadic large conifers (red cedar and douglas fir) provide the canopy. The understory is composed of vine maple, salmon berry, ferns, blackberry, ivy, nettles, skunk cabbage, sedge and devils club. From RM 0.7 to 1.1, the ravine narrows to 200 - 500 feet but still provides a significant buffer from residences and a golf course. In this reach, the one- to three-percent-gradient stream flow diminishes by about one third, and the channel is devoid of pools (as was the adjacent lower reach). Landslides are apparent through this reach and the vegetation is similar to the previous but much more dense, especially near the flowing channel. A landslide has formed a large pond (in 1997 it was 120 feet long x 40 feet wide x 3 -6 feet deep) at RM 1.0. In 1997, this slide material was considered a significant risk to downstream habitat because of the potential that it could remobilize and create a dam break event (Nelson, 1997).

LARGE WOODY DEBRIS

LWD is virtually absent in all Hamm Creek tributaries. Given the state of riparian zone, any near-term natural recruitment is precluded.

HYDROLOGY

The changes in the flow regime of all forks of Hamm Creek have been extensively altered by a variety of anthropogenic impacts. These include increases in impervious surfaces associated with industrial development and urbanization, channelization and piping, dredging, and removal of wetlands, riparian vegetation and LWD. All of the forks of Hamm Creek exhibit flows typical of lowland western Washington streams in urbanized settings. Stream flows increase quickly to rainfall events and decrease quickly upon the cessation of rainfall. Some of the reaches that are not confined in pipelines show evidence of stormwater impacts, such as the lower mile of the Middle Fork where streambed incision and channel widening has been observed (King County 1995a).

The Rainier Golf and County Club diverts water from the South Fork Hamm Creek out of a ditch into two ornamental ponds. A pump house located adjacent to the lower of these two ponds then supplies water to an ornamental concrete-lined pond on a golf course fairway.

Flows were measured at 1.3 cfs on January 11, 1996 and 1.5 cfs on May 21, 1997 (King County 1995a).

SEDIMENT CONDITION

Long reaches of all forks are contained in pipes and culverts, and many of the stream reaches outside the pipes are in highly channelized ditches. This is particularly true of the reaches that are on the valley floor. The low gradient of all forks once they reach the valley floor has resulted in the accumulation of large quantities of fine gravels, sands and silts which dominate the substrate (King County 1994, King County 1995a). In locations where moderate or larger gravels are located, they are cemented with considerable amounts of fines. The lack of suitable spawning gravels is a habitat-limiting factor to natural salmonid production.

WATER QUALITY

Stream flows in all forks of Hamm Creek have exhibited evidence of water quality degradation typical of streams in urbanized settings during storm events. Metals such as zinc, copper, and lead have been measured at high concentrations during these storm events. In addition to the high metal concentrations, high concentrations of total suspended solids and total petroleum hydrocarbons (TPH) have been measured at sampling locations throughout the streams with only minor exceptions (King County 1994, King County 1995a).

Elevated pH with values up to 8.72, sampled during base flow conditions, have been attributed to runoff from a cement kiln dust pile located in the vicinity of South 96th Street and 10th Avenue South (King County 1994).

During mid 1997, a fish kill occurred from the flushing of chlorinated water from the local water purveyor pipeline into the South Fork Hamm Creek near Des Moines Way.

LAND USE

Land use within the basin is dominated by residential and commercial/industrial uses. Open space is typically occupied by public right-of-ways (i.e.: Seattle City Light transmission lines) or golf course property. There are some mixed deciduous/coniferous second growth forests, especially in the bluffs that the tributaries transect. Table Hamm-2 shows land use acreage and percent of basin occupied by these land uses.

Table Hamm-2: Land Use in Hamm Creek (Source: King County 1994).

Residential	Commercial/Industrial	Open Space
850 acres (61%)	242 acres (17%)	316 acres (22%)

The percent of effective impervious surface was not located during the course of this investigation. But because in excess of 88 percent of the land was in either residential or commercial/industrial use as determined in 1994, it is expected that the percent of impervious surfaces in this basin is quite high.

NON-NATIVE SPECIES

ANIMALS

There are no known non-native aquatic animal species in Hamm Creek.

PLANTS

There are numerous plant species associated with ornamental plantings throughout all of the forks. Thickets of reed canarygrass, ivy, Himalayan blackberry, and bittersweet nightshade dominate numerous stream reaches (King County 1994). The thicket in these reaches serves to constrict stream channel flow and present a lack of channel complexity and habitat necessary for salmonid production.

HYDROMODIFICATION

As detailed previously in this chapter, the stream channels of all forks of Hamm Creek have been extensively modified (table Hamm-2) from historic uses. The insufficient amounts of stream associated structure and the habitats it would create that are necessary for support of various life phases of salmonids effectively limits their natural production.

Table 1: Hamm Creek (09.0002) Stream Channel Types and Distances* (Source: King County 1995a).

Stream Name	Piped (feet)	Confined Ditch (feet)	Otherwise Modified (feet)	Unmodified (feet)
Mainstem of Middle, North & Lost Forks	1,925	785	0	0
South Fork	770	1,350	1,470	3,885
Middle Fork	825	1,160	2,500	750
North Fork	2,875	0	500	0
Lost Fork	1,800	300	0	0

* Distances are approximate.

OFF CHANNEL HABITAT

Several South Fork Hamm Creek stream enhancement efforts have occurred recently. An off-channel wetland-pond and stream channel enhancement project at “Point Rediscovery” has been constructed in 1996 and 1998 between Highway 99 and Des Moines Memorial Drive (about RM .5) at the old Rainier Vista treatment plant site.

FLOODPLAIN CONNECTIVITY

Many of the stream reaches have been disconnected from the floodplain and tightlined or channelized by development. Low-gradient riffles and shallow pools dominate the lower reaches of all forks that might have been utilized by salmonids for natural production.

The condition of the channels of all of the forks of Hamm Creek limit natural salmonid production.

KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- Naturally producing anadromous salmonids may be absent from most of this subbasin. Presently, only the lower 0.7 of South Fork Hamm Creek contains any potential spawning habitat for anadromous salmon for the subbasin.
- There is utilization by coho salmon of only the South Fork Hamm Creek.
- All forks of Hamm Creek suffer from an particularly severe system of piping and channelization.
- A combination of stream sediment load, stream channel characteristics, and high flows during storm events adversely impact anadromous fish success.
- Water quality in the lower stream reaches is particularly degraded by metals, TSS and TPH.
- Outside of the bluff-associated ravines, the riparian habitat (where present) is composed of numerous non-native plant communities.
- The stream channels generally lack complexity due to the lack of LWD, vertical channel migration, and bank armoring. Instream structures are needed to produce channel complexity for successful salmonid production.
- The quality and quantity of gravels in the stream limits anadromous and resident salmonid spawning potential juvenile rearing success.
- There are only limited amounts of off-channel habitat suitable for juvenile salmonid rearing and holding.
- Access to the Middle and North Forks is limited by the outlet into the Duwamish River and the amount of piping present throughout these streams.
- While the percent of effective impervious surfaces in these streams was not found as a part of this investigation, the amount and type of land use in this subbasin indicates that the percent would quite high.

EARLY ACTION RECOMMENDATIONS

- The water quality, sediment regime, and hydrology of this subbasin has been severely degraded and could undermine stream enhancement efforts A thorough, scientific evaluation of the production potential of this system for a naturally sustaining stock of salmonids should be conducted prior to further resource expenditure.

LIST OF TABLES

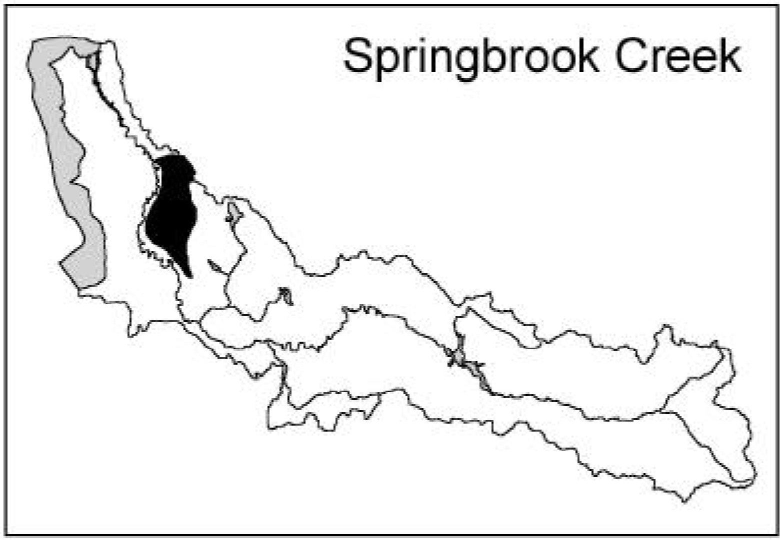
Table Hamm-1: Hamm Creek (09.0002) Stream Channel Types and Distances* (Source: King County 1995a).

Table Hamm-2: Land Use in Hamm Creek (Source: King County 1994).

3.3 SPRINGBROOK CREEK SUBBASIN

Physical Description 2
Subbasin 2
Stream Course and Morphology 3
Salmonid Use 3
Factors of Decline 4
Fish Passage 4
Riparian Condition 7
Hydrology 10
Sediment Condition 10
Water Quality 11
Land Use 13
Non-Native Species 13
Hydromodification 13
Key Findings and Identified Habitat-limiting Factors 15
Data Gaps 15
Early Action Recommensations 15

3.3 SPRINGBROOK CREEK SUBBASIN



PHYSICAL DESCRIPTION

SUBBASIN

Springbrook Creek (09.0005) Subbasin is located east of the mainstem Green River, in and around the cities of Kent and Renton. The Springbrook Creek subbasin enters the mainstem Green River via the Black River at RM 11.0. With an estimated mainstem stream length of 12.0 miles, and approximately 19.1 miles of tributary streams and 3.8 miles of drainage ditches (Williams 1975), it is the largest subbasin in the lower Green River Basin. Springbrook Creek subbasin drains an area of about 15,763 acres

The basin is comprised of two distinct physical settings. In the eastern half of the subbasin, rolling hills rise to elevations of about 525 feet above the valley floor. In this area, the origins of stream courses are often not well defined. Slopes in the subbasin range from near 0 to 70 percent. One significant lake is present (Panther Lake) along with several smaller ponds and wetlands. Creeks originating from these upland sources drop abruptly through sharply defined steep canyons to the valley floor where stream gradients flatten quickly. Typically, these canyons are short, with high gradients and generally not accessible to anadromous salmonids

A unique feature to this subbasin in the Black River Pump Station, the details of which will be covered in the Hydromodification section of this chapter. Except where indicated by specific citations, the following descriptions of the Springbrook Subbasin comes from a comprehensive fisheries assessment of the Mill, Garrison and Springbrook Creek system conducted by Harza (1995).

STREAM COURSE AND MORPHOLOGY

Instream potential fish habitats include approximately 5.8 miles within Springbrook Creek, 6.65 miles in Mill Creek, and 5.2 miles in Garrison Creek. The specific habitat types are summarized in table Springbrook-1.

TABLE SPRINGBROOK-1: SUMMARY OF VARIOUS HABITAT TYPES IN THE SPRINGBROOK CREEK SUBBASIN

Habitat Type	Springbrook Creek		Mill Creek		GARRISON CREEK	
	Length (ft)	Percent	Length (ft)	Percent	Length (ft)	Percent
All Potential Fish Habitat	30,645	100	35,096	100.0	27,456	100.0
Steps	40	< 1	0.5	<1	0	0
Pools	54	<1	627	2	40	<1
Riffles	4,174	13	7,555	22	1,420	5
Glides	0	0	886	3	225	1
Low Gradient Glides	25,304	83	26,023	74	14,488	53
Habitats Not Delineated	1,073	4	0	0	11,283	41
Source: Harza 1995						

The western half of the subbasin lies on the valley floor and stream gradients are virtually flat. Mill and Garrison Creeks are the primary tributaries. Both have their origins in the eastern foothills before dropping quickly through the respective steep ravines. The stream labeled by Harza (1995) as the Valley Floor Fork Garrison Creek was depicted by Williams (1975) as Springbrook Creek. In this report we will use the Williams (1975) descriptor and numbering system (09.xxxx). The Garrison Creek subbasin consists of the three forks: North Fork (09.0023), Middle Fork (09.0022) and South Fork (09.0025), and an unnamed tributary to the South Fork (09.0024).

SALMONID USE

The known freshwater distribution of anadromous salmonids is depicted in the report Appendix. Coho salmon, cutthroat trout, and winter steelhead adults have been observed spawning in Springbrook Creek and its tributaries (WDFW Spawning Ground Survey Database., R. Malcom pers. comm.). Juvenile hatchery origin coho salmon have also been released routinely in upper reaches of several tributary streams. Adult chinook have been observed entering the Black River (R. Malcom pers. comm.) and attempting to spawn near the SW 27th Street culvert during the fall of 1997 (P. Schnieder pers. comm.). It is hypothesized that they are exploring this system, but once they enter the Black River via the fish ladder at the Black River pump station there is no mechanism for them to exit.

Juvenile coho, winter steelhead, and cutthroat have been captured at numerous locations throughout the subbasin. (Williams 1975, Harza 1995, R. Malcom pers. comm., P. Schneider pers. comm.). Approximately 17.9 stream miles of potential fish habitat exist within the Springbrook Creek subbasin. Of this amount, approximately 17.2 miles is believed to be accessible to anadromous salmonids (Harza 1995).

FACTORS OF DECLINE

FISH PASSAGE

The most significant fish passage barrier in this system is the presence of the Black River Pump Station. In 1958, the Black River Dam (an earth-filled dam) was completed on the Black River approximately 1,000 feet upstream of its confluence with the Green River. The purpose of this structure was to control outflows from the Black River and prevent flows on the Green River from backing up into the Black River/Springbrook Creek floodplain during floods. Six 48-inch diameter culverts extended through the dam and were fitted with flapgates. In 1972, the U.S. Soil Conservation Service (SCS) (renamed the Natural Resources Conservation Service) replaced the dam with the current Black River Pumping Station (BRPS), to provide a means of releasing flood flows from the Black River/Springbrook Creek system when the Green River is at high stage. The BRPS is currently operated and maintained by King County Surface Water Management.

During flood periods on the Green River, the pumping station acts as a dam, preventing floods from backwatering into the Black River and the wide valley floor of the lower Springbrook Creek subbasin. Water levels downstream of the pumping station range from –4.0 to +21.5 feet MSL, depending on tidal conditions and the water level of the Green River. Water surface elevations upstream of the pumping station are normally held in the range of 0.0 to 2.0 feet, but can reach as high as 13.0 feet. The pumping station consists of a series of eight pumps, and can pass flows of up to 2,945 cfs. Two large pumps with a capacity of approximately 1,028 cfs are also present, but have not yet been used.

The BRPS represents a barrier to upstream passage of salmonids. In addition, the ability to control the water surface elevations upstream of the BRPS often results in situation where the downstream water surface is higher than the upstream water surface. In order to pass upstream and downstream migrating salmonids around the structure, a unique fish passage system has been constructed and is in operation. A combination of a fish ladder and fishway chute is used for upstream passage. Fish migrating downstream are diverted around the pumps using an air-lift pump to raise the fish to the downstream water levels. The general layout of the BRPS and fish passage facilities is illustrated by Figure Pass-11.

UPSTREAM PASSAGE

Upstream passage facilities are located on the south side (left bank) of the pumping station, and consist of a combination fish ladder and fishway chute (Figure Pass-12). The main components of the upstream fish passage facility are a water supply pump, denil fish ladder, a false attraction weir, and a fish way chute. Fish enter the denil fish ladder, swim up and over the false weir and are then returned to the river upstream of the project via the fishway chute.

The denil ladder extends from the downstream pool on the south side of the BRPS approximately 60 feet horizontally and 14 feet vertically to a resting pool below the false weir. From the resting pool, fish enter the second portion of the ladder that extends 25 feet horizontally and seven feet vertically to the top resting pool. The velocity of the 5 cfs flow directed through the ladder is approximately 2.5 to 3.0 feet per second. This velocity is well within the normal range for this type of ladder and is suitable for adult salmon (Bell 1986). However, these velocities are at the upper limit of sustained swimming speeds for juvenile fish (Bell 1986), and thus likely prevent upstream migration of juvenile fish.

From the top resting pool, fish pass over the false weir and down the fishway chute. The fishway chute drops from approximate elevation 16.0 feet to 2.0 feet, creating a potential vertical drop of 2.0 feet at the end of the chute when the upstream water surface is held at 0.0. The 60 foot long chute is an open channel for the first 10 feet, a closed pipe for 25 feet and ends in an open channel for the final 25 feet. The inside of the chute is coated with vinyl to protect fish from abrasion. Two 30-degree angles in the closed section are used to align the chute parallel to the forebay south (left bank) wingwall.

The upstream passage facility is normally operated from mid-September through 31 January of each year. Before 1993, the upstream passage facility was usually operated 24 hours per day, Monday through Friday. Since 1993, the upstream passage facility has been operated about 24 hours per day, seven days per week, during the seasonal window. The operational window likely precludes the upstream migration of some adult resident and anadromous cutthroat trout and anadromous steelhead.

The species composition of fish migrating upstream was assessed in 1994 by trapping adult fish in a net pen installed in the forebay of the BRPS, immediately below the outflow of the fishway chute (Harza 1995). A total of 229 coho salmon and 14 chinook were trapped between 17 September and 9 December (Harza 1995). Fair coho spawning habitat was noted in some reaches, although the streambed appeared to be unstable and flow levels may have been insufficient for successful spawning (Harza 1995). The facility is not equipped to handle downstream migrating adult steelhead (kelts) or chinook. Adult steelhead and chinook that move upstream past the BRPS cannot exit the Springbrook Creek subbasin, and once there are believed to experience high levels of stress or be killed outright prior to successful spawning (Harza 1995).

DOWNSTREAM PASSAGE

The downstream passage facilities provide a means of transporting juvenile salmonids migrating towards the ocean around the BRPS. The downstream fish passage facility consists of entrance fish ports and associated piping, an air lift system, deaeration tank and transport pipe (Figure Pass-13). Fish travelling through the system enter the downstream passage facility through the fish ports on the upstream side of the dam. The fish are then transported to the air lift system and into the deaeration tank. Fish exit the deaeration tank via a bypass pipe that delivers them to the pool downstream of the dam.

The entrance ports to the system are located at elevation +2.0 and –2.0 on the south wingwall (left bank) and are adjacent to the fish screens for the pumps on the south half of the structure on the south side of the BRPS (Figure Pass-13). The airlift pumps draw flow into the transport pipes, attracting fish to the entrance ports. Fish travelling downstream move across the screens and into the ports. Except for the two large pumps, fish are prevented from entering the pumps by galvanized 0.25-inch mesh screens. To date the large, unscreened pumps have not been used during the late winter or spring (April to June). A visual inspection of the screens in March 2000 provided some concerns that the screens may not meet current screening criteria. The facility was not designed to meet salmonid swimming approach velocities that are now required of facilities under construction.

After entering the fish ports, the fish descend a vertical fiberglass pipe to elevation –17.0 feet, and are then directed towards the airlift through a horizontal collection pipe. As the horizontal pipe passes into the airlift chamber, it turns vertically 90 degrees and descends to elevation –39.0 feet. At this point, the fish go through two more 90 degree elbows, then enter the airlift pump. Air added at –39.0 feet displaces water at the base of the vertical column, lifting the fish to +13.0 feet and into the deaeration tank.

The dimensions of the five-foot deep deaeration tank are 9.5 feet x 9.5 feet. The entrance to the 18-inch diameter fiberglass downstream transport pipe is located at the west end of the tank. This pipe transports fish approximately 108 feet horizontally to the fishway exit. The exit invert pipe is at 10.0 feet elevation, which can vary in height above the receiving water; normally, the drop is approximately 6 feet from the pipe to the receiving water. There is the potential for drops to reach 14 feet under low flow circumstances.

The downstream passage facility is operated from early April to mid-June each year, for approximately eight hours per day, Monday through Friday. Fish attempting to move downstream outside of that operational window are either prevented from exiting the Springbrook Creek subbasin, or must pass through the unscreened large pumps (if operational). Juvenile chinook emerge and begin moving downstream in the middle Green River system and Soos Creek as early as February (J. Kerwin pers obs., Jeanes and Hilgert 2000; Hilgert and Jeanes 1999), thus early downstream migrants may be prevented from exiting the Springbrook Creek subbasin.

The known anadromous fish barriers are summarized in table Springbrook-2. This table likely underestimates the number and types of barriers to anadromous and resident fish because a comprehensive fish barrier assessment has not been initiated for this subbasin.

Table Springbrook-2: Springbrook Creek Subbasin Fish Passage Barriers

Creek Name/Number	**Barrier Type**	**Location**
Springbrook/09.0005	Water quality	Lower reaches
Mill Creek/09.0015	Water quality	Lower reaches
Mill Creek/09.0015	Culvert (unverified concern)	Earthworks Park Detention Pond
Springbrook/09.0005	Culvert	At Talbot Road
S.F. Springbrook/09.0024	Concrete pad & weir	At Talbot Road
Springbrook/09.0005	Diversion	Springbrook trout farm
Springbrook/09.0005	Culverts choked with brush & aquatic vegetation	Throughout creek
M.F. Garrison/09.0022	Braided channel/wetland	Between 212^{th} & 218th
N.F. Garrison/09.0023	Culvert	212^{th} Way

There exists a barrier in the North Fork Garrison Creek at the South 212^{th} Street road crossing. This culvert has a wide concrete chute which is thought to have been designed to distribute flow energy. There is at least a 3.5 foot drop immediately below this chute with no plunge pool present.

The Unnamed tributary (09.0020) Harza (1995) refers to this tributary as Springbrook Creek) has a 2-½-foot step with no plunge pool immediately east of the SR 167 crossing. While not believed to be a blockage to adult salmonids it could prevent instream movement of juvenile salmonids. Between the SR 167 crossing and Talbot Road the creek flows through a private trout farm. These ponds present a migrating barrier for anadromous salmonids for both 09.0020 and a tributary 09.0021.

Several sections of Springbrook Creek are so choked with invasive reed canarygrass and vegetation that they serve as partial barriers. The Springbrook Trout Farm serves as a barrier, under most streamflow situations, to anadromous fish upstream migration. If the bypass reach is dewatered then it would also serve as a barrier to downstream migration. Upstream of the trout farm, Springbrook Creek flows through a 30-foot culvert that is sloped at approximately 100 percent in the vicinity of Talbot Road. On the South Fork Springbrook Creek there is a concrete pad and notched weir that likely is a barrier to upstream and downstream migrating anadromous and resident fish.

Water quality may serve to act as a barrier to anadromous migrating fish in the lower reaches of Mill and Springbrook Creeks.

A culvert in the North Fork Garrison Creek was believed to be impassable in 1993 (Harza 1995). Additionally, those same investigators thought the highly braided channel in the middle Fork Garrison Creek that traversed the wetlands between 212th Way and South 218th Streets may be impassable.

RIPARIAN CONDITION

The riparian habitats in this subbasin range from bare banks to remnant coniferous forest fragments.

In Springbrook Creek, the Black River Pump Station creates a slackwater pond of approximately 3 surface acres. The actual surface acreage is dependent on specific water surface elevations. Riparian vegetation around this pond consists of willow species (*Salix sp.*), Pacific dogwood (*Cornus nuttallii*), cattails (*Typha latifolia*), reed canarygrass (*Phalaris arundinacea*) and red alder (*Alnus rubra*).

As the creek moves upstream out of the inundation reach, the riparian habitat changes slightly to a mixture of red alder, willow species, Himalayan blackberry and sedges (*Carex spp.*) along with some ornamental trees. Conifers are almost exclusively absent and in those areas where shade was absent reed canary grass is abundant. From the 16th Street crossing upstream to the confluence with Mill Creek, Springbrook Creek resembles a drainage ditch with reed canary grass the dominant vegetation with only token numbers of black cottonwood, willow and alder present. Ribbonleaf pondweed (*Potamogeton epihydrous*) was also identified in this reach.

Construction practices observed in the basin in the 1990s indicated vegetation removal to the water's edge.

From the confluence of Mill Creek upstream to the State Route 167 highway crossing the stream more closely resembles a drainage ditch. Reed canarygrass is the dominant riparian vegetation.

Sloughing of the streambank was common in places. From the State Route 167 highway crossing upstream to Talbot Road the stream lost its drainage ditch appearance but still did not have a function riparian zone. A right bank tributary stream at RM 5.2 (09.0020) upstream of the Talbot Road crossing enters an area protected by the City of Renton for municipal water supply. An unnamed tributary (09.0020) flows from a gabion water control structure while the south fork (09.0021) flows from a small reservoir. Harza (1995) labeled these tributaries as north and south forks of Springbrook Creek.

Springbrook Creek continues mostly parallel and adjacent to State Route 167 with reed canarygrass and Himalayan blackberry bushes the dominant riparian habitat. Again, the creek more resembles a drainage ditch used for water conveyance. Red alder was found sporadically throughout this reach with very little instream structure. During the 1993 Harza survey, there were instances of vehicles parked adjacent to the waters edge preventing the establishment of any vegetation.

In summary, riparian habitat within this creek meets the NMFS criteria of not properly functioning and is a limiting factor to natural salmonid production.

In Mill Creek, from its confluence with Springbrook upstream past the West Valley Highway to the East Novac Valley Road, the dominant riparian vegetation was reed-canary grass with minor amounts of red alder and black cottonwood (*Populus trichocarpa*). At some places in this reach, dredging of the creek has created vertical banks and other areas have contoured banks with approximately 4:1 slopes. In many segments, this reach resembles a drainage ditch. Very few riparian trees or shrubs were observed during a habitat survey in 1993.

Mill Creek flows within 5 feet of an apartment complex in the Kent City limits. The primary riparian vegetation consisted of reed canarygrass and a few black cottonwoods. Considerable instream garbage is a problem in the reach near Memorial Park in Kent. It is approximately this point (RM 8.5) that the historic Springbrook Creek as shown in Williams (1975) was diverted into Mill Creek. Because of that diversion we will continue to label this stream as Mill Creek.

Mill Creek flows through the Earthworks Parks Detention Pond (EPDP), a water detention structure that lacks trees, and shrubs. Additional trees were planted in 1994 in an effort to provide riparian habitat. Upstream of the EPDP the character of the stream changes as it enters a forested ravine dominated with red alder and bigleaf maples. Black cottonwood, Douglas fir and western red cedar are also present.

Upstream of the EPDP, the character of the creek changes dramatically as it enters a forested ravine with predominantly red alder and bigleaf maples. There are also black cottonwood, Douglas fir and western red cedar present along with an understory of salmonberry and vine maple. This creek has its origins at an ornamental pond before moving downstream through an open swale upstream of 274th Street.

Garrison Creek is a right bank tributary that enters Springbrook Creek at RM 6.25 and is comprised of three forks (North (09.0023), Middle (09.0022) and South (09.0024)). The South Fork Garrison Creek has one tributary (09.0025) that is accessible to anadromous salmonids.

The lower reaches of Garrison Creek are typical of a drainage ditch with riparian vegetation comprised predominantly of reed canarygrass and Himalayan blackberry plants. Sporadic red alder trees were present during the 1993 Harza survey. Woody vegetation is generally absent in the riparian zone throughout the lower reaches downstream of 88th Avenue South. Upstream of State Route (SR) 167, the Middle Fork Garrison Creek (09.0022) riparian habitat changes slightly as more red alders and Himalayan blackberries are present. The habitat survey conducted by Harza (1995) indicates the presence of a wetland upstream of SR 167. This wetland has a riparian habitat consisting of black cottonwood, red alder, bigleaf maple, pacific willow (*Salix lasiandra*), pacific dogwood (*Cornus nuttallii*), Himalayan blackberry and willow species. An understory of sedge, rush and bulrush species is also present.

Upstream in the reach from SE 218th Street to the confluence of the South Fork there have been several attempts at streambank restoration, including planting of non-native deciduous trees. Investigators involved in the Harza (1995) survey thought most of the attempts to be ineffective at that time.

The creek flows from the foothills through a relatively short steep gradient ravine vegetated with older bigleaf maple, red alder, black cottonwood, Douglas fir and western hemlock. Streamside canopy cover was estimated at 90 percent in 1993.

The North Fork Garrison Creek (09.0023) has a riparian vegetation zone consisting of red alder and bigleaf maple with an understory of salmonberry and blue elderberry (*Sambucus cerulea*). Streamside shade was estimated at 80 percent.

The South Fork Garrison Creek (09.0024) and an unnamed tributary (09.0025) share a high gradient shot ravine with a riparian zone vegetated by older bigleaf maple, red alder, black cottonwood, Douglas fir and western hemlock. Streamside shade in these tributaries was estimated at near 100 percent.

LARGE WOODY DEBRIS

In Springbrook Creek, the area parallel and adjacent to State Route 167 the instream substrate consists exclusively of silts and contains no LWD.

Once Mill Creek enters the forested ravine upstream of the EPDP, LWD is present in this upper reach but has not been inventoried or measured. This LWD is believed to have been deciduous tree in origin and less than 50 years old. However, it is responsible for adding channel complexity, creating pools and sorting of sands and gravels. LWD is absent from the area near EPD as well as the lower reaches of the creek.

LWD is present in Garrison Creek, upstream of the confluence with the South Fork Garrison Creek and is thought to help sort sediments. In the South Fork Garrison Creek, upstream in the reach from SE 218th Street to the confluence of the South Fork, LWD (conifer logs) and boulder clusters is present due to streambank restoration projects. LWD is present in the North Fork Garrison Creek upstream from its mouth but has not been inventoried or measured.

HYDROLOGY

Springbrook Creek flow has an annual yield of about 40 cfs.

Bortz (1981) concluded that the most serious condition existing in these streams was the extreme volumes of water associated with storm events. Harza (1995) reported that water quantity responded quickly after each storm event. Hydrographs indicated that the creek stage decreased after the conclusion of each storm event. This is typical of streams in urban areas that have relatively high impervious surface areas. In stream systems that have greater permeable surface areas, flow stage decreases more slowly thus allowing for a more efficient utilization by fish and other aquatic organisms of the increased instream flows (Lucchetti and Furstenberg 1992).

There currently are two US Geological Survey (USGS) stream gages in this subbasin. USGS gage number 12113346 is located in Garrison Creek and 12113349 is in Mill Creek. Together, Mill and Hill creeks drain approximately 14.5 square miles (~60 percent of the subbasin). Based on the most recent 5 years for water years 1995 through 1999 the combined annual yields for these two tributaries is approximately 29 cfs. The one-day average annual minima/maxima for the same time period and combined gage records is approximately 3.1 cfs with the individual tributaries average annual minima between 1 and 1.5 cfs. The Garrison Creek system, which is smaller than the Hill Creek system produces more annual yield (Burkey pers comm). Because of stream gage location, these analyses do not include the lower 40 percent of Springbrook Creek subbasin.

SEDIMENT CONDITION

As previously stated in the hydrology section, Bortz (1981) observed that extreme volumes of water associated with storm events caused streambank erosion, scouring and siltation in the three creeks. Harza (1995) found evidence of severe downcutting in Mill and Garrison Creeks and low to moderate downcutting in Springbrook Creek.

It is likely that construction practices observed in the basin in the 1990s which removed vegetation to the water's edge was a significant contributor to sediment entering Springbrook Creek. [Location is ambiguous. See Draft original page 2 Riparian Habitats, Springbrook Creek, paragraph 4.] The lower reaches of Springbrook Creek are in the slack water pond behind the BRPS and upstream as far as the SR 167 crossing the instream substrate consists exclusively of silts.

The upper reaches of Mill Creek have been extensively modified. According to anecdotal information, the historic upper reaches of Mill Creek used to flow through a gravel bedded channel. The headwaters are now a poorly channelized swale as the result of excavation and backfilling in an historic riparian wetland. Once Mill Creek enters the forested ravine upstream of the Earthworks Parks Detention Pond, there are patches of gravel suitable for spawning present. The first evidence of sands is seen in the vicinity of the EPDP. The lower reaches of Mill Creek are typical of low-gradient streams and are composed primarily of silt. Also in this reach, instream garbage increases. Bank erosion is present where Mill Creek flows within 5 feet of an apartment complex in the Kent City limits.

The North Fork Garrison Creek upstream from its mouth has numerous small and large boulders present, apparently recruited from streambanks. Gravel patches, while not plentiful were present.Those streambanks without large boulders present showed numerous signs of erosion in the 1993 habitat survey.

On Garrison Creek, as the stream gradient increased upstream in the vicinity of SE 218th Street, the streambed substrate was comprised of primarily gravel with some silt, sand and cobbles. upstream of the confluence with the South Fork Garrison Creek had increasing amounts of gravel with some cobble and boulders. The streambanks are comprised of highly erodible alluvial soils consisting of sand and gravel. Once Garrison Creek enters the ravine, the instream substrate was predominantly gravel, cobble and boulders. There were signs of erosion in this ravine during a 1993 habitat survey. The lower reaches of Garrison Creek are comprised of silts and fine sands typical of low-gradient streams and the drainage ditch that it resembles.

The South Fork Garrison Creek instream substrate is very different from the other forks of Garrison Creek. The stream substrate is a mixture of cobble, boulder and bedrock and significant portions of the streambank were observed to have eroded in the 1993 habitat survey. Investigators from Harza (1995) observed several rock gabions in the canyon. A pipe from the top of the ravine led into these gabions and they were possibly being used as erosion protection.

WATER QUALITY

Water quality within the Springbrook subbasin has been the subject of several intensive studies. Those studies and their focus area are shown in table Springbrook-3.

Table Springbrook-3: Water Quality Studies of the Springbrook Subbasin		
Investigator (Date)	**Study Title**	**Focus Subject**
Renton (1993)	Black River basin water quality management plan	Water quality, erosion and sedimentation
Parametrix (1992)	Mill Creek erosion control project	Water quality in upper Mill Ck. And literature review
Herrara (1990)	City of Kent Water Quality Assessment	Water quality
Parametrix (1990)	Mill Creek water quality monitoring report	Water quality
Wilsey and Ham (1972)	Mill Creek answer book	Water quality
Entranco (1992)	Garrison Creek wetland/erosion control facilities	Water quality and erosion
Resource Planning Associates and Herrara (1991)	City of Kent water quality program 1992-1996	Water quality
Bortz (1981)	Streambed, habitat, beneficial use and recommendations towards enhancement of Kent stream ecosystems	Water quality

These studies are important in that many report similar water quality parameter concerns (table Springbrook-4). Concentrations of metals that acutely affect salmonids differ according to site specific water chemistry parameters. Copper has been demonstrated to have adverse impacts on rainbow trout and chinook fry at 20 and 18 ug/liter respectively. Lead has been demonstrated to have adverse impacts to salmonids at levels <20 ug/liter while zinc levels at 10, 9 and 103 ug/liter adversely impact 7 gram rainbow trout, cutthroat trout and chinook fry respectively.

Table Springbrook-4: Reported Concentrations of Metals of Concern in the Springbrook Creek Subbasin

Metal	Water Body	Concentration (ug/liter)	Flow Conditions	Reference
Copper	Springbrook Ck.	2.7 – 3.9	base flow	Renton 1993
Copper	Springbrook Ck.	10.8 – 11.3	Storm flow	Renton 1993
Copper	Springbrook	5.0	NA	Harza 1995
Copper	Mill Creek	4.0 – 12.0	Storm flow	Parametrix 1990
Copper	Mill Creek	(1)	NA	Bortz 1981
Lead	Springbrook Ck.	0.5 – 0.7	Base flow	Renton 1993
Lead	Springbrook Ck.	8.1 – 11.7	Storm flow	Renton 1993
Lead	Mill Creek	2.0 – 14.0	Storm flow	Parametrix 1990
Lead	Springbrook Ck.	2.7	NA	Harza 1995
Lead	Mill Creek	(1)	NA	Bortz 1981
Zinc	Springbrook Ck.	117.0 – 154.0	Base flow	Renton 1993
Zinc	Mill Creek	19.0 – 88.0	Storm flow	Parametrix 1990
Zinc	Mill Creek	1560.0	Base flow	Bortz 1981
Zinc	Springbrook Ck.	32	NA	Harza 1995
Cadmium	Mill Creek	< detection limit	NA	Parametrix 1990
Cadmium	Mill Creek	(1)	NA	Bortz 1981
Chromium	Mill Creek	(1)	NA	Bortz 1981

(1) State water quality parameters were exceeded but no values provided.

One of the single most important environmental variables influencing the reproductive success of salmonids is water quality. Poor water quality may be responsible for direct mortality or indirectly impact adult salmonids through increasing metabolic demands.

The Springbrook Creek subbasin appears on the EPA Clean Water Act 1996 and 1998 303(d) lists for water quality violations (Table xxx NOTE: This table will be included at a later date) for high temperature and low dissolved oxygen levels at multiple locations low in the subbasin. Low dissolved oxygen levels have been reported by numerous sources at sampling locations throughout the subbasin and appear to be a chronic seasonal occurrence. These water quality violations are believed to be the result of low water flows, lack of adequate riparian vegetation and shade, point and non-point pollution sources (Harza 1995). Low dissolved oxygen levels in water decreases the swimming stamina and respiratory efficiency in fall chinook salmon when levels are below 5 mg/l (Smith et. al 1971).

The presence of heavy toxic metals is thought to work synergistically with other water quality environmental stresses to further compromise fish health. A low pH in water results in an increase in the amount of metal ions in solution. This in turn increases the potential for juvenile and adult salmonids to be adversely affected by the toxic effects of these heavy metals.

During 1994, adult chinook salmon entered the BRPS between September 17 and October 22. Water temperatures during this same time period were as high as 19.5 C at the Mill Creek USGS gage and 20.2 C at the BRPS location. At the same time, the dissolved oxygen levels at the Mill Creek gage averaged 4.5 mg/l with a range from 0.9 mg/l to 10.1 mg/l. Temperature, dissolved oxygen and percent saturation levels at the lower levels of this rangeare lethal to adult chinook salmon, juvenile coho, cutthroat and steelhead (Piper et al 1982).

In 1994, coho salmon that entered the Springbrook Creek subbasin before October 26 would have faced similar lethal water quality issues as chinook. It was only after the first large storm of the season that year that most water quality parameters began to improve. However, Parametrix (1990) suggested that concentrations of heavy metals in Mill Creek increase during the first storm event after a dry period. The rapid influx of heavy metals at this time would almost certainly have placed these adult coho under additional stress and compromised their reproductive success.

Investigators in the 1993 Harza habitat survey noted dead trees and shrubs on both sides of Mill Creek in the vicinity of the West Valley Highway and South 204th Street. A culvert with a reddish discharge was observed entering Mill Creek immediately upstream of the area of dead trees. Subterranean iron was also observed upwelling in Mill Creek immediately downstream of 76th Avenue South.

LAND USE

No information.

NON-NATIVE SPECIES

ANIMALS

Eight species of fish were captured during the 1993 Harza habitat surveys. Pumpkinseed sunfish (*Lepomis gibbosus*) were the only non-native species identified. A total of 26 pumpkinseed sunfish were captured, of which 25 were captured in Mill Creek and 1 in Springbrook (downstream of the confluence with Mill Creek). Pumpkinseed sunfish are also reported to be present in the detention pond in upper Mill Creek in the vicinity of 104th Avenue SE.

PLANTS

Reed canarygrass (*Phalaris arundinacea*) is abundant throughout this subbasin and was historically removed by dredging. Although it can provide some streambank erosion protection functions, it generally affords minimal fish habitat and prevents native shrubs and trees from becoming established in the riparian habitat zone.

Private property owners have planted riparian areas in non-native species of maple, willow and cherry trees in limited sections of the Middle Fork Garrison Creek.

Japanese knotweed (*Polygonum cuspidatum*), an aggressive non-native weed that spreads rapidly in moist environments, was found in a wetland associated with Springbrook Creek between Highway 167 and Talbot Road.

HYDROMODIFICATION

The entire Springbrook Creek subbasin has been adversely impacted by floodplain modifications. The most significant of which is the Black River Pump Station. BRPS initially consisted of an earthen dam constructed in 1958. The dam was located on the Black River approximately 1,000 feet upstream of the confluence with the Green River and designed to control outflows from the Black River and prevent flows on the Green River from backing up into the Black River/Springbrook Creek floodplain during periods of high water. In 1972, the U.S. Soil Conservation Service (SCS) replaced the dam with the BRPS, to provide a means of releasing flood flows from the Black River/Springbrook Creek system when the Green River is at high flows. Currently, the BRPS is operated and maintained by King County Surface Water Management.

During flood periods on the Green River, the pumping station acts as a dam, preventing water from backing upstream into the Black River and the wide valley floor of the lower Springbrook Creek subbasin. Water levels downstream of the pumping station range from –4.0 to +21.5 feet MSL, depending on tidal conditions and the water level of the Green River. Water surface elevations upstream of the pumping station are normally held in the range of 0.0 to 2.0 feet, but can reach as high as 13.0 feet. The pumping station consists of a series of eight pumps, and are designed to pass flows of up to 2,945 cfs. Two large pumps with a capacity of approximately 1,028 cfs are also present, but have not yet been brought on line.

The BRPS represents a barrier to the upstream passage of salmonids. In addition, the ability to control the water surface elevations upstream of the BRPS often results in situation where the downstream water surface is higher than the upstream water surface. In order to pass upstream and downstream migrating salmonids around the structure, a unique fish passage system has been constructed and is in operation. A combination of a fish ladder and fishway chute are used for upstream passage. Fish migrating downstream are diverted around the pumps using an air lift pump to raise the fish to the downstream water levels. The general layout of the BRPS and fish passage facilities are illustrated by Figure Pass-11.

The upper reaches of Springbrook Creek shown in Williams (1975) have been diverted into Mill Creek (09.0015). The date and reason for this diversion are not clear to individuals involved in this report.

OFF CHANNEL HABITAT

Information describing the current or historic extent of the floodplain in the Springbrook Creek subbasin is scarce, and it is unknown whether channelization, bank armoring or disconnection of off-channel habitats have influenced off-channel habitat connectivity.

No information was made available during the course of this report to assess either the historic or existing extent or condition of off-channel habitat in the Springbrook Creek subbasin.

FLOODPLAIN CONNECTIVITY

The Springbrook Creek subbasin is isolated from the Green River floodplain by the Black River Pump Station discussed previously in this chapter. While there was no direct information provided during this report, it is evident that the creeks in this subbasin have undergone extensive alterations to their historic stream channels by their drainage ditch appearance, right angle turns along property lines and straight channel lines.

KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- Historically, it is believed that these creeks were important areas of refugia to anadromous salmonids that reared year round in the Green River basin.

- Water quality is degraded throughout much of this subbasin.

- There is no functioning riparian habitat throughout the lower reaches of Mill and Springbrook Creeks. This absence of this habitat contributes to the lack stream channel diversity, complexity and ultimately successful salmonid rearing capabilities.

- The Black River Pump Station is a partial fish passage barrier and does not meet current fish screening criteria. Adult salmonids that migrate upstream of this structure cannot migrate back into the mainstem Green River because of facility design.

- There are several known barriers to adult salmonid fish passage in Springbrook, Mill and Garrison Creeks. Some of these barriers are seasonal and/or dependent on annual precipitation patterns.

- Degraded water quality throughout the lower reaches of Springbrook and Mill Creeks adversely impact adult chinook and coho reproductive success along with coho, cutthroat and steelhead juvenile survival.

DATA GAPS

- No information was available during the course of this report to assess either the historic or existing extent or condition of off-channel habitat in the Springbrook Creek subbasin.

- The extent to which plant and animal non-native species are impacting salmonid survival is not fully understood. A comprehensive assessment of non-native species needs to be initiated, completed and action plan developed.

- The diversion of the upper reach of Springbrook Creek into Mill Creek appears to occur in the vicinity of downtown Kent. Information was not readily available regarding the diversion method which could be a barrier to upstream access.

- There was no land use information easily accessible for use in this report.

EARLY ACTION RECOMMENSATIONS

- Conduct a comprehensive fish barrier survey to determine the full extent of lost habitats

- A quantitative baseline habitat inventory needs to be undertaken.

LIST OF TABLES

Table Springbrook-1: Summary of Various Habitat Types in the Springbrook Creek Subbasin

Table Springbrook-2: Springbrook Creek Subbasin Fish Passage Barriers

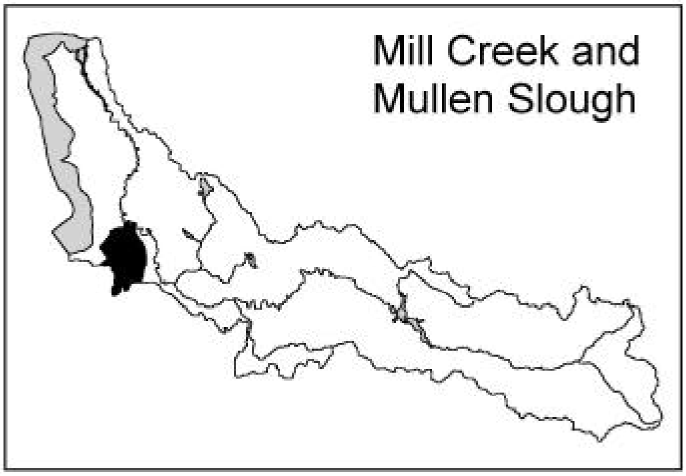
Table Springbrook-3: Water Quality Studies of the Springbrook Subbasin

Table Springbrook-4: Reported Concentrations of Metals of Concern in the Springbrook Creek Subbasin

3.4 MILL CREEK AND MULLEN SLOUGH SUBBASIN

Physical Description 2
  Subbasin 2
  Stream Course and Morphology 2
  Salmonid Use 3
Factors of Decline 4
  Fish Passage 4
  Riparian Condition 5
  Hydrology 5
  Sediment Condition 6
  Water Quality 6
  Land Use 9
  Non-Native Species 9
  Hydromodification 9
Key Findings and Identified Habitat-limiting factors 12
Data Gaps 13
Early Action Recommendations .... **Error! Bookmark not defined.**

3.4 MILL CREEK AND MULLEN SLOUGH SUBBASIN



PHYSICAL DESCRIPTION

SUBBASIN

For the purposes of this report, the Mill Creek (09.0051; sometimes referred to as Hill Creek in literature sources) and Mullen Slough (09.0045) subbasin is defined as an area bordered by Kent to the north, Algona to the south, the valley wall to the west, and the Green River channel to the east. It includes all areas and tributaries that drain into:

- Mill Creek and tributaries (09.0052, 09.0054, and 09.0055);
- Mullen Slough and tributaries (09.0046, 09.0047, 09.0048, and 09.0049);
- Midway Creek (09.0041) and tributary (09.0043); and
- The northeast Auburn Drainage Systems (09.0056, 09.0058, 09.0059, 09.0060, and 09.0065) that flow independently into the Green River.

All of these drainages are included in this chapter because they share a similar geographic location and a sizeable floodplain immediately adjacent to the mainstem Green River. Together, these tributaries constitute the second-largest subbasin to the Lower Green River.

STREAM COURSE AND MORPHOLOGY

Mill Creek is a left-bank tributary that joins the Green River at approximately RM 23.9. Its stream length is approximately 8.35 miles (Williams 1975). The basin is comprised of two distinct physical settings.

In the western half of the Mill Creek subbasin, rolling hills rise to elevations of 300 – 400 feet above the valley floor. In this area, the origins of stream courses are often not well defined. Four significant lakes (Dolloff, Fenwick, Geneva and Star) are present, along with several smaller ponds (such as Bingaman Pond (09.0049)), and wetlands. These lakes and seeps are the headwater sources for Mill Creek, Midway Creek, Mullen Slough and their respective tributaries. Creeks originating from these upland sources drop abruptly through sharply defined steep canyons to the valley floor, where stream gradients flatten quickly. Typically, these canyons are short and have high gradients. The notable exception is Mill Creek, which drops through a sizeable ravine (Peasley Canyon) before entering the valley floor.

The eastern half of the subbasin lies on the valley floor and stream gradients are virtually flat. Mill Creek and Mullen Slough are the primary drainage courses of this section. Historically, both Mill Creek and Mullen Slough conveyed water received from nearby wetlands to the mainstem Green River, served as important flood storage areas, and provided refugia to anadromous salmonids from winter high flows.

Several studies have examined the Mill Creek subbasin in recent years. The most pertinent of these studies are outlined in the table Mill-1 below. The objective of most of these studies has been flood control (some even refer to Mill Creek as a "conveyance channel" (King County, undated) It is only recently that restoration initiatives have been examined. There have been at least eight other studies (table Mill-1) that also examined hydraulic issues in the Mill Creek subbasin.

Table Mill-1. Summary of Some Pertinent Mill Creek Subbasin Studies.

Study Title	Sponsor/Author	Study Objectives
West Side Green River Watershed Workplan (1965)	Soil Conservation Service, King County, Auburn, Kent, Tukwila, Renton	Flood protection
Urban Drainage Study for the Green River Valley (1974)	Seattle District Corps of Engineers	Flood control
Mill Creek Basin Profile (1980)	Basin Technical Committee	Flood control
Mill Creek Water Quality Management Plan (1993)	King County and Washington Department of Ecology	Flood and water quality issues.
Reconnaissance Report No. 4, Mill Creek Basin (1987)	King County	Compilation of flooding, erosion, water quality and habitat problems
Mill Creek Basin Study (~ 1988)	King County	Flood control
Mill Creek Flood Control Plan (Phase II)	King County, Auburn and Kent	Flood control
Mill Creek Basin, Aquatic Resources Restoration Plan (1997)	Auburn, Kent, King County, Environmental Protection Agency, Corps of Engineers	Guidance for aquatic resource restoration and enhancement

SALMONID USE

MILL CREEK

The known freshwater distribution of anadromous salmonids is depicted in the report Appendix. Coho, chum, and winter steelhead adults have been observed spawning in Mill Creek (Washington Department of Fish and Wildlife *Spawning Ground Survey Database* 1998;

Malcom 1999). Because of the low stream gradients and the anthropogenic barriers to anadromous fish in Mullen Slough and its tributaries, spawning ground surveys are not routinely conducted in this system. Juvenile coho, chum, winter steelhead, cutthroat and chinook have been captured in Mill Creek (Williams 1975; Malcom 1999; Schneider 1999).

MULLEN SLOUGH

Juvenile coho salmon and cutthroat and rainbow trout are documented as using Mullen Slough and portions of its tributary system (Malcom 1999; Shannon and Wilson 2000). Harza (1999) notes chinook and chum salmon juveniles present near the confluence with the Green River (from pers. comm. with R. Malcolm June 9, 1998).

FACTORS OF DECLINE

FISH PASSAGE

MILL CREEK

Historically, anadromous fish migrated up Mill Creek at least as far as approximately RM 6.7. Portions of the short, high-gradient canyons of this subbasin may have been accessible to anadromous salmonids.

However, numerous road culverts block access. For example, tributary 09.0049 (which flows into and out of Bingaman Pond) is blocked by three road culverts (45th Avenue South, 46th Avenue South, and 55th Avenue South). Coho salmon and cutthroat trout habitat suitable for spawning and rearing has been reported upstream of Bingaman Pond (Finney pers. comm.). Currently, an impassable culvert at approximately RM 5.0 blocks anadromous fish passage. The stream reaches of Mill Creek upstream of Peasley Canyon Way South are not currently accessible to anadromous salmonids due to a road culvert and King County paving of the streambed immediately upstream of the culvert. The concrete trapezoidal channel has been identified as a complete barrier to all upstream fish passage (D. Finney pers. comm.).

Stream channel constrictions as a result of debris left by illegal dumping has been implicated in some reaches as a serious problem (Auburn et al. 1997).

MULLEN SLOUGH

Barriers to resident and anadromous fish populations are significant throughout Mullen Slough and its tributaries. A potential low-flow barrier occurs at the confluence of Mullen Slough with the Green River. The cause of this potential barrier is not fully understood but is believed to be from a combination of wetland filling, water withdrawal, and the hydrologic maturity of the watershed.

Other flow barriers (channel encroachment by reed canary grass, and beaver dams) occur throughout the valley floor above and downstream of 277th Avenue bridge.

Anthropogenic barriers in the form of hanging culverts occur at the base of the valley floor for tributaries 09.0046 and 09.0049. Several culverts may be partial or complete barriers to anadromous fish during some flows occur in the agricultural lands of the valley floor. In addition, the wetland above 277th Avenue may impede fish access to the upper reaches of streams 09.0045, 09.0047, and 09.0048.

RIPARIAN CONDITION

A comprehensive riparian assessment has not been completed in this subbasin. The riparian habitat conditions that have been examined, of Mill Creek vary from fair to poor, with some reaches rated as high possibility of recovery while others as unrecoverable (Auburn 1997). However, the 1979 report, *River of Green* (King County 1979) provides an important insight to the habitat losses of the previous 18 years from its publication date.

The riparian areas in these streams do not meet any criteria of properly functioning riparian habitat. Development has greatly eliminated functioning riparian habitat along the stream courses. Once it enters the valley floor, Mill Creek riparian habitat generally consists of small stands of early-growth deciduous trees and borders of non-native shrubs and grasses. Remnant stands of native vegetation are rare. This fragmentation effectively limits where interconnections between formerly functioning elements of the larger ecosystem can be restored. The lack of a functioning riparian habitat is a major limiting factor to natural salmonid production in these streams.

LARGE WOODY DEBRIS

Comprehensive surveys for the presence of LWD were not located during the development of this report for this subbasin. However, it was the professional judgement of fisheries biologist and ecologists involved in the development of this document (Green River Technical Advisory and Factors of Decline Group, 2000) that LWD is extremely limited within the anadromous zone of this subbasin.

Additionally, the current status of riparian habitats within the anadromous zone generally precludes any recruitment of LWD within the next 80 to 100 years. There is more potential for recruitment of LWD from the ravines of the valley wall, as they contain relatively mature stands of a mixed coniferous/deciduous forest.

HYDROLOGY

MULLEN SLOUGH

Mullen Slough has its headwaters from several small streams originating from the uplands along the west side of the Green River valley wall. Three such small streams originate from the outflow of Bingaman Pond, Star, and Fenwick lakes. The later stream flows intermittently while the former flow throughout the year.

The remainder of the system is contained within the valley floor, where it maintains its historic low gradient in the valley floor. Historically it is believed to have functioned as important over-wintering refugia for anadromous salmonids from flood flows.

SEDIMENT CONDITION

MILL CREEK

Erosion in the upper reaches, especially in the ravines along the valley wall has been identified as an adverse impact (King County, undated; King County 1993; King County 1996).

Sedimentation problems in the lower reaches were identified in a former report. Since the last major rain events (1990, 1996), extensive amounts of stream-associated sediments have been transported downstream and areas of the Mill Creek floodplain, and wetlands in Auburn and Kent have been filled and/or eliminated as part of development in the lower valley. This filling of wetlands may cause low-lying and unfilled areas to flood during the next major storm event. The effect on fish could include stranding out of the channel and pollutant collection by the floodwaters.

Some contributory factors include sediments from borrow pit and construction sites, erosion along the streambank in Peasley Canyon, and runoff from urban and agricultural sources.

MULLEN SLOUGH

Because of its low gradient, only limited areas of suitable spawning gravels were believed to have been historically present. These gravels would have been in areas of upwelling groundwater and above existing anadromous barriers that have long since disappeared.

Today, sedimentation problems believed to originate from nearby agricultural lands and their conversion to light industry continues to plague this stream. The slough suffers from extensive ditching in its lower reaches and can best be characterized as a drainage ditch in this area. Exposed banks are common in both the ravines and valley floor and most likely are a source of turbidity and sedimentation. Sediments in the lower reaches of Mullen Slough have high biological oxygen demand and nutrient concentrations.

WATER QUALITY

MILL CREEK

Mill Creek is designated as a Class A stream by the Washington State Department of Ecology (WDOE). However, water quality has become so degraded throughout the Mill Creek system that it appears on the federal Environmental Protection Agency (EPA) 303(d) list in 1996 and the 1998 (see table Mill-2) candidate list for numerous water quality excursions beyond acceptable limits.

Table Mill-2. EPA Clean Water Act 303(d) 1998 Candidate List Parameters and Locations for Mainstem Green River Tributaries (WRIA 9).		
Stream	**Sampling Location (RM)**	**Parameter**
Springbrook	1.5	Dissolved oxygen
	1.5	Temperature
	0.1	Temperature
	0.1	Dissolved oxygen
Mill Creek	1.4	Temperature
	0.3	Dissolved oxygen
	0.2	Temperature
	0.2	Dissolved oxygen
	1.0	Dissolved oxygen
	2.2	Dissolved oxygen
	2.2	Temperature
Mullen Slough	0.5	Dissolved oxygen
	0.5	Temperature
	1.6	Dissolved oxygen
	1.6	Temperature
Newaukum Creek	5.2	Dissolved oxygen
	10.1	Dissolved oxygen
Soos Creek	1.0	Dissolved oxygen
Little Soosette Creek	3.1	Dissolved oxygen
	3.9	Dissolved oxygen
Little Soos Creek	3.2	Temperature
	4.7	Dissolved oxygen
	10.5	Dissolved oxygen
Gale Creek	0.3	Temperature

Water quality was also cited as a degraded by several studies including the Municipality of Metropolitan Seattle (Metro) Draft Priorities for Water Quality (Metro 1989), and the Mill Creek Water Management Plan (Metro 1993). The sampling station at the mouth of Mill Creek maintained by Metro showed the lowest overall water quality of the 44 sites monitored in the Green River valley (Metro 1989). The stream exhibits water quality degradation through:

- Low dissolved oxygen levels;
- Seasonal high water temperatures;
- Streambank erosion and associated water turbidity; and
- High nutrient concentrations (i.e., phosphorus, nitrate, and ammonia).

WDOE and EPA standards for dissolved oxygen, water temperature, turbidity and fecal coliform bacteria are commonly not met. While fecal coliforms are typically of greater concern as a human health threat, they are an indicator of overall water quality and biological oxygen demand (BOD) (King County 1993).

Additionally, especially associated with storm events, the stream water has elevated levels of heavy metals which exceed state and federal water quality standards (King County 1993).

Seasonal high stream water temperatures are linked to low flows, low water velocity and lack of riparian canopy.

An extreme dissolved oxygen sag has been detected between West Main Street in Auburn and 29^{th} Street NW. Dissolved oxygen levels in this reach drop to as low as 3 mg/l. The minimum dissolved oxygen level for salmonids is considered to be 5 mg/l and the state water quality standard is 8 mg/l. Factors believed to be contributing to these low dissolved oxygen levels include;

- Demand from accumulated organics trapped in the reed canarygrass;
- High BOD from pollutants;
- High benthic demand;
- Low gradient of the stream that results in low reaeration rates; and
- Increased seasonal stream temperatures due to lack of suitable canopy (which has also been identified as the primary factor affecting stream temperatures (King County 1996)).

Water quality degradation from point and non-point pollution sources as well as turbidity caused by land clearing and development has also been identified as requiring corrective action (Auburn et al. 1997).

MULLEN SLOUGH

Mullen Slough exhibits much of the same water quality degradation as Mill Creek. Several water quality studies (Shapiro 1989; King County and Ecology 1993) point to exceedance of state and federal standards for temperature, dissolved oxygen, fecal coliform, turbidity, un-ionized ammonia, and total phosphorous and nitrate. Water quality studies (Shapiro 1989)suggest that heavy metals are in lower concentrations than Mill Creek.

The slough appears on EPA’s 1996 303(d) list and the 1998 candidate list for excursions beyond allowable criteria for both dissolved oxygen and water temperature. These temperature and low dissolved oxygen violations occur during seasonal low flows in the late summer in Mullen Slough because:

- It is a low-gradient stream;
- Much of its channel is choked with thick concentrations of reed-canary grass;
- It lacks riparian canopy; and
- Its historical wetlands have been removed.

LAND USE

MILL CREEK

Throughout the western area of this subbasin, increased residential development has removed large tracts of forested areas. Impervious surfaces in the Mill Creek subbasin were estimated at 20 percent in 1986, with total build out predictions of 45 percent in upland areas and 70 percent in lowland areas (Author Unknown 1988). These figures were for total impervious areas and are not reflective of effective impervious areas.

MULLEN SLOUGH

Impervious surfaces are significant in the upper reaches of Mullen Slough.

NON-NATIVE SPECIES

FISH

A single large channel catfish (*Ictalurus spp)* has been captured in Mill Creek (Malcom pers. comm.). Other warmwater fish species, including yellow perch (*Perca fluviatilus*), pumpkinseed sunfish (*Lepomis gibbosus*), goldfish (*Carassius auratus*), black crappie (*Pomoxis nigromaculatus*), largemouth bass (*Micropterus salmoides*) and smallmouth bass (*M. dolomieui*) are found in many of the headwater lakes of this subbasin (Cropp pers. comm.). The lakes that these fish typically inhabit do not have any structures (screens) that would prevent them from migrating out of the lake or being washed out during a period of high flow. Thus, it is assumed that these fish are present in Mill Creek, but their numbers are significantly small enough to not turn up in previous electroshocking surveys, and as such they are not believed to be a limiting factor.

PLANTS

Reed canarygrass (*Phalaris arundinacea*) and Himalayan blackberry (*Rubus procerus*) are abundant throughout this subbasin. King County conducted a mapping project to assess the existing and potential threats of invasive, non-native aquatic plants in King County Lakes during 1994 and 1995. That report, published in 1996 (Walton 1996) examined lakes Dolloff, Geneva and Star in this subbasin, and found Eurasian watermilfoil (*Myriophyllum spicatum*) in Dolloff and Star lakes. However, these are currently outside the geographic distribution of naturally producing salmonid populations and therefore do not have an immediate adverse impact to salmonids. A 1999 survey of Lake Geneva found Purple loosestrife (*Lythrum salicaria*) and reed canarygrass (King County 2000).

HYDROMODIFICATION

MILL CREEK

The historic stream channel of Mill Creek and its tributaries have been significantly altered and constrained in a variety of ways. In some places, they are diverted from the natural channel and placed into straight channels or ditches. Often this was done to meet the needs of landowners so that the creek would be the defining property boundary line. At other times, channels were altered during road construction to facilitate drainage.

The construction of State Route 167 and the expansion of the associated road network further constricted the ability of Mill Creek to migrate laterally. In the mid 1980s, the reach of Mill Creek from 29th Street N.W. to 37th Street N.W. was relocated parallel to SR 167 to allow construction of the Puget Power Christopher Substation as part of the Mill Creek Restoration (relocation) Plan. The new 100-year flood capacity channel was slightly meandered, and revegetated with shrubs and trees. More recently, the stream reach from 37th Street NW to the north was relocated in a similar fashion to allow a warehouse construction (Finney, pers. comm.).

Mill Creek has at a minimum 21 road crossings that are comprised of a mixture of culvert and bridge types. The construction of State Route 167 resulted in the movement of Mill Creek from its historic channel into its current location.

MULLEN SLOUGH

The entire Mullen Slough has undergone a systematic change from historic uses. Historically these channels and streams are thought to have been important flood storage uses. Today, the upper tributary reaches, ravines, and hillsides have been culverted and channelized by suburban development. Reaches along the valley floor are also heavily channelized, although few road crossings and culverts exist in lower Mullen Slough. The stream channel has three bridge crossings; two at the mouth and one on 277th Avenue.

OFF CHANNEL HABITAT

MILL CREEK

Wetlands temper peak flows by slowly releasing storm waters, protecting vital fish habitat from damages due to erosion and sedimentation.

However, much of Mill Creek's historical wetland complexes have been divided up and drained/ditched to improve agricultural lands or development. As noted in Land Use (above), this subbasin's high level of impervious surfaces causes adverse impacts to streams (Booth 1997).

Approximately 2,400 acres of remaining wetlands were inventoried in 1996/97, and the type and acreage are shown in table Mill-3.

Table Mill-3. Existing Wetland Types and Acreage in Mill Creek Subbasin.	
Wetland Type	**Acreage**
Emergent	1,870
Scrub-shrub	108
Forested	236
Open water	213
Total	2,427
Source: Auburn et al 1997.	

The majority of the forested and open water wetlands are in headwater and hillside areas of the basin. Approximately half of the open water acreage (101 acres) is contained in the four major lakes in this subbasin.

Of the 1,870 acres of emergent wetlands, the majority was in some type of agricultural use in 1996-97. The King County Farmland Preservation Program (KCFPP) preserves approximately 900 of those acres for agricultural purposes only. Approximately 650 of the KCFPP acres contain wetlands. These 650 wetland acres represent the last remaining large tract of land in the entire subbasin that is free of impervious surfaces. It is therefore an important potential area for salmonid stream ecosystem restoration.

MULLEN SLOUGH

For anadromous salmonids, the low-gradient lower river streams such as Mullen Slough were historically more important as over-wintering refugia from flood flows than as suitable spawning habitats. In the larger ecosystem, these streams provided an important tool for anadromous salmonids survival. In addition, palustrine streams like Mullen Slough most likely offered good rearing habitat for anadromous and resident salmonids during all but the driest summer months.

Currently, because of extensive ditching and water diversions, much of the habitat complexity of Mullen Slough is lost and the system can no longer properly function at its historic level of productivity.

FLOODPLAIN CONNECTIVITY

MILL CREEK

Within the Mill Creek subbasin, Auburn et al. (1997) identified 14 corridor wetland sites that were suitable for restoration.

Under current conditions, flooding of this subbasin is strongly influenced by backwater effects of the mainstem Green River, and as a result of locally generated runoff. High flows in the Green River can result in the inundation of up to 900 acres of primarily agricultural land in the Mill Creek and Mullen Slough subbasins (Army Corps of Engineers 1997).

MULLEN SLOUGH

Auburn et al. (1997) identified an additional eight off-corridor wetland sites that were suitable for restoration in the Mill Creek and Mullen Slough subbasins. Flooding in Mullen Slough is caused by either high water levels in the mainstem Green River that cause water to back up the tributary or as a result of increased surface flows due to increases in impervious surfaces in the subbasin. King County (1996) found that flooding in the backwater sections of Mullen Slough is exacerbated by the increasing volumes and rates of runoff from new development in the subbasin, in both the valley floor and upland slopes.

KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- Mill Creek continue to support spawning of adult coho salmon and juvenile rearing of coho, cutthroat, steelhead, and to a limited extent chinook. Chinook adults were reported to have been observed in Mill Creek in 1999.
- Mullen Slough most likely supports rearing of coho, cutthroat and steelhead along with some cutthroat trout spawning.
- The remaining riparian habitats are fragmented.
- Some of poorest water quality conditions sampled in the Green/Duwamish River occur in Hill Creek and Mullen Slough.
- Water quality is a significant adverse issue impacting anadromous fish productivity and survival.
- Much of the floodplain area is agricultural and within the Farmland Preservation Program.
- Numerous fish blockages are present from degraded water quality, low-flow barriers, and culverts. Unlike many lower Green tributaries, no flap gates or pumping stations are present at the confluence of Mill Creek or Mullen Slough and the Green River.
- Channel relocations have resulted in a simplification of stream channel configuration that limits diversity.
- Impervious surfaces that exceed 20 percent in Mill Creek contribute significantly to storm-associated flood flows.
- Road-associated culverts block anadromous fish access to significant upstream portions of streams in this chapter.
- There is a significant lack of LWD and associated stream habitat complexity throughout the streams in this subbasin.
- Although no quantifiable information was available, it was the professional judgement of the TAG that flood flows due to increased impervious surfaces limit successful salmonid incubation.

- Degraded water quality, streambed condition, invasive and non-native plant species, lack of a properly functioning riparian buffer, channel complexity, floodplain connectivity, and suitable pool quality and quantity all limit natural salmonid production.

DATA GAPS

- Comprehensive barrier surveys need to be initiated in this subbasin.
- Comprehensive base line riparian habitat and bank condition surveys should be initiated.
- An inventory of LWD should be initiated.
- Very little data was found on Midway Creek.
- Historic channel location information needed.
- Comprehensive review of the effects of non-native plant species (reed canarygrass and Himalayan blackberry) on aquatic biota should be documented.

LIST OF TABLES

Table Mill-1. Summary of Some Pertinent Mill Creek Subbasin Studies.

Table Mill-2. EPA Clean Water Act 303(d) 1998 Candidate List Parameters and Locations for Mainstem Green River Tributaries (WRIA 9).

Table Mill-3. Existing Wetland Types and Acreage in Mill Creek Subbasin.

3.5 EAST HILL TRIBUTARIES OF THE LOWER GREEN RIVER

Physical Description 2
Subbasin 2
Stream Course and Morphology 2
Salmonid Use 3
Factors of Decline 3
Fish Passage 3
Riparian Condition 4
Hydrology 5
Sediment Condition 5
Water Quality 6
Land Use 7
Non-Native Species 8
Hydromodification 8
Key Findings and Identified Habitat-limiting Factors 8
Data Gaps 9
Early Action Recommendations 9

3.5 EAST HILL TRIBUTARIES OF THE LOWER GREEN RIVER

PHYSICAL DESCRIPTION

SUBBASIN

This chapter will cover the following streams (identified by local names and/or Williams' (1975) catalog number system):

- Olson Creek [09.0061];
- Lea Hill Creek [09.0069];
- Cobble Creek [09.0068]; and
- The Hillside Drainages [09.0068A-G].

In addition, there are numerous unnumbered channels and ditches that are included where information on them was provided.

Booth et al. (1994) summarized many of the conditions of these tributaries, and most of the information in this chapter is attributed to that report unless otherwise noted.

The boundaries of these creeks follow drainage basin lines but can be defined as those areas east of the Soos Creek subbasin, south of the Mill Creek subbasin and tributaries west and south to the Green River from approximately River Mile 28.5 to 30.0. These eastern tributaries that flow into the Lower Green River share many of the same attributes, including headwater locations on the east Kent plateau, drainage basin size and land use.

Historically, all of these stream systems traversed old-growth coniferous forests, down the relatively steep hillsides into the Green River Valley where stream gradients flattened before flowing through extensive wetland complexes prior to entering the mainstem Green River. The old-growth forests were removed beginning approximately 140 years ago, and the valley floor was then converted to agricultural purposes. During the last 25 years, this subbasin has been rapidly urbanized, a trend that continues today. Most of the wetlands historically found on the valley floor have been filled, drained or otherwise altered.

STREAM COURSE AND MORPHOLOGY

OLSON CREEK

Olson Creek drains approximately 1,022 acres, with approximately three miles of defined stream channel. Most of this stream system lies on the upland plateau between 350 and 500 feet in elevation. Williams (1975) identified two tributaries (09.0064 and 09.0063).

Olson Creek is formed from surface water of two Class 2 wetlands (King County Sensitive Areas Map Folio—Wetland Criteria 1990). A third wetland drains into the combined flow of the first two at a series of constructed ornamental ponds at RM 1.08 just before the creek descends steeply through Olson Canyon to the valley floor.

LEA HILL CREEK

Lea Hill Creek drains approximately 406 acres and has approximately one mile of defined stream channel. It enters the left (east) bank of the Green River at approximately RM 30.15. Most of the subbasin lies on the upland plateau between 400 and 450 feet in elevation.

Its primary source is a forested swamp on the north side of SE 312th Street immediately upstream of 116th Avenue S.E. A secondary source lies in the vicinity of 112th Avenue S.E., where two large gullies have eroded from the road's end into the main stream channel.

COBBLE CREEK

Cobble Creek drains approximately 165 acres and is less than one mile long. Ames (1981) identified this creek as entering the right (east) bank of the Green River at RM 30.05. Most of the subbasin lies in areas of the valley floor and east wall.

The source of Cobble Creek appears to be surface runoff.

THE HILLSIDE DRAINAGES

The Hillside Drainages are a series of short streams originating a short distance above the bluff line. They are mentioned here because of their historic effects rather than current utilization by anadromous and resident salmonids.

SALMONID USE

The known freshwater distribution of anadromous salmonids is depicted in the report Appendix.

Historically, these creeks were thought to contain year-round populations of coho salmon, cutthroat trout and steelhead trout.

Williams (1975) either did not list these streams, or indicated that their utilization by anadromous salmonids was unknown. The WDFW Spawning Ground Survey Database (1999) does not note the presence of adults of any salmonid species in any of these creeks. Juvenile coho have been observed in several creeks (Booth 1994), but are probably the result of hatchery fry releases (Baranski 1999).

FACTORS OF DECLINE

FISH PASSAGE

OLSON CREEK

The upper limit of anadromous fish access on Olson Creek is defined by a natural 10-foot-high waterfall located at RM 0.49.

A culvert under Green River Road has been identified as a partial barrier at approximately RM 0.05.

An alluvial fan episodically builds out where Olson Creek enters the mainstem Green River channel (see Sediment Condition—Olson Creek). The alluvial fan may form a temporary access barrier until it erodes away each fall.

LEA HILL CREEK

A near-vertical 6- to 8-foot-high waterfall at RM 0.75 marks the historic upper extent of anadromous access. Downstream of this point, fish passage barriers are numerous throughout the stream. Within the alluvial fan between RM 0.13 and 0.25, loss of channel definition may cause temporary passage barriers depending on seasonal flows. The large concrete pipe under Green River Road (RM 0.13) periodically fills with sediment and small organic debris that can block anadromous fish passage.

COBBLE CREEK

A perched culvert blocks anadromous fish access as it enters the right (east) bank of the Green River at RM 30.05.

THE HILLSIDE DRAINAGES

In their original configurations, these drainages would have been important temperature and flooding refugia for overwintering anadromous salmonids. At present, upstream movement of salmonids from the Green River mainstem into many of these tributaries is blocked, and most of the remaining utilization by salmonids is the result of hatchery supplementation.

RIPARIAN CONDITION

OLSON CREEK

In the stream reach downstream of the confluence with 09.0061B, Olson Canyon widens and the riparian corridor consists of a deciduous second-growth forest. Between RM 0.65 and 0.17, the riparian corridor is somewhat intact and better functioning. However, downstream of RM 0.17, Olson Creek lacks any functioning riparian cover.

LEA HILL CREEK

The riparian habitat varies considerably throughout the Lee Hill Creek channel system. Second-growth coniferous and deciduous trees are present within the headwater wetland. Dead coniferous trees in one portion of the wetland are evidence of recent hydrologic changes. Sometime between 1981 (when the King County Wetlands Inventory was prepared) and 1994 (when King County carried out a reconnaissance study in this group of subbasins), approximately 20 percent of this headwater wetland was eliminated during the construction of the Auburn Hills Mobile Court.

At approximately RM 0.78, the stream channel begins a rapid descent to the valley floor through a high-gradient ravine. Historically a mature old growth coniferous forest, this uneven-aged second growth deciduous forest presently provides adequate shading for the creek. Once the creek reaches the valley floor, the riparian zone largely consists of a narrow to nonexistent band of deciduous trees, willows and non-native plant species including reed canarygrass and Himalayan blackberry.

Downstream of SE 116th Street, the stream channel is confined within a 70-foot-wide forested corridor. Lawns border the edge of the stream in several places and there is no intact riparian canopy.

COBBLE CREEK

The riparian habitat in this stream ranges from fair to degraded.

THE HILLSIDE DRAINAGES

As can be expected given current levels of urbanization in these subbasins, current riparian habitats range from degraded to fair.

LARGE WOODY DEBRIS

Olson Creek

Remnant old-growth coniferous stumps are still present in the riparian corridor and streambed downstream of the confluence of Olson Creek with 09.0061B. However, most of the remaining LWD in the stream is small and of poor quality, suggesting that LWD sources have decreased and/or LWD has been deliberately removed from the stream channel over the past hundred or so years. The channel character changes in the vicinity of RM 0.3 – 0.4, where incision has been less than one foot over the last several decades. Instream LWD is more abundant although no counts or volume estimates have been made. LWD is again virtually absent downstream of RM 0.17.

Lee Hill Creek

At approximately RM 0.78, Lee Hill Creek descends rapidly to the valley floor through an uneven-aged second growth deciduous forest that provides some degree of LWD recruitment. Numerous old-growth stumps are also present on the hillside and in the creek.

HYDROLOGY

Hydrologic information on these systems is limited at this time.

SEDIMENT CONDITION

In general, Booth’s 1994 study determined that sediment quality exceeded state standards. Modeling of study parameters indicates that large-scale future development will likely result in future sediment degradation.

OLSON CREEK

Anthropogenic activities appear to have increased the rate of erosion of the naturally unstable hillslopes within this subbasin, compared to rates of erosion that carved the original stream channel. Increased erosion and sedimentation in Olson Creek is the result of clearing of trees on the steep slopes to enhance views, piping of stormwater by inadequately engineered water conveyance systems, and grading activities. However, no data is currently available to quantify these sediment loads.

At RM 0.48, tributary 09.0061B enters Olson Creek from the north. This tributary descends off the plateau at such a steep gradient that it has eroded a large gully that has delivered several hundred cubic yards of sediment into Olson Creek . The recruitment of this material is believed to be slowing as less loose material remains. The deposition of coarse sediments is particularly evident between RM 0.0 – 0.8. An alluvial fan episodically builds out into the mainstem Green River channel and erodes away each fall.

LEA HILL CREEK

As would be expected of a stream system with such a high impervious area, erosion and sediment loads are major factors contributing to the poor functioning of this stream. The upper portion of the ravine is rapidly incising. Between November 1990 and November 1994 it was estimated that approximately 3,000 cubic yards of sediment had entered Lea Hill Creek from this source alone. Other smaller gullies also exhibit erosion problems. Channel incision and landslides are ubiquitous between RM 0.75 and 0.3. Once the creek reaches the valley floor and the stream gradient decreases, these sediments settle out, forming multiple high-flow channels that wind across an alluvial fan that covers the valley floor between RM 0.25 and 0.13. Spawning gravels are limited and often times cemented with fine sediments that settle out in the low-gradient reaches of the valley floor. The large concrete pipe under Green River Road (RM 0.13) periodically fills with sediment and small organic debris.

COBBLE CREEK

Neither flooding nor erosion are believed to be major problems. No major wetlands remain in the subbasin, and fine sediments along the entire stream channel now cement any remaining gravels.

WATER QUALITY

None of these creeks currently appear on the EPA Clean Water Act 303(d) list for water quality impairments. However, although this list is extensive in scope, numerous bodies of water may not appear on this list due to lack of adequate assessments. Booth (1994) examined a number of water quality parameters and modeled future pollutant loadings within this group of subbasins. Overall, for the parameters examined, stream water quality was determined to exceed state standards. Modeling of these parameters indicates that water quality will continue to exceedence state and federal standards.

LAND USE

All of the tributaries lie either wholly or mostly within the King County Urban Growth Boundary and on lands that are already urbanized, or expected to undergo future urbanization. Typically, urbanization is responsible for the degradation of both the form and function of the downstream aquatic ecosystem, as is the case in all of these systems.

The level of impervious surfaces adjacent to these streams is significant. Table East Hill-1 shows the level of land use as of 1992 and, where available, the projected impervious surface area at grow-out.

EH-1: Land Use of the East Hill Tributaries to the Green River

	Olson Creek	Lea Hill Creek	Cobble Creek	Hillside Drainages
Wetland	88.1	11.3	0.0	11.2
Forest	202.5	167.7	54.5	748.8
Grass	230.9	34.2	11.0	91.0
Single Family (low density)	469.2	110.5	54.7	296.0
Single Family (high density)	22.3	43.5	44.8	185.0
Multifamily	2.5	2.0	0.0	22.1
Industrial/Commercial	6.2	36.8	0.0	1.3
Total Acres	1021.7	406.0	165.0	1355.4
1994 Total Effective Impervious Surface (%)	3.0	11.7	8.1	5.1
Projected Total Effective Impervious Surface (%)	18.0	33.0	20.0	15.0

OLSON CREEK

Urban development has been slower in the Olson Creek subbasin than in many others addressed in this chapter. Standard provisions in King County and local jurisdiction sensitive area ordinances or similar regulations govern current development. In 1994, the effective impervious area was determined to be 3 percent, primarily in the form of low-density single family residences. However, future zoning would allow the impervious surface to increase to a projected 18 percent (Booth 2000), which will almost certainly have an adverse impact on aquatic resources.

LEA HILL CREEK

Urban development has been extensive in this subbasin. In 1994, 12 percent of this subbasin was covered with impervious surfaces, and impervious area was projected to climb to 33 percent under buildout conditions. This impervious area is largely of multifamily residential developments and two schools.

COBBLE CREEK

Urban development has been substantial in this subbasin. In 1994, the total impervious surface area was measured at 8 percent, and is projected to reach 20 percent at buildout.

THE HILLSIDE DRAINAGES

Development within all of these small watersheds consists of a mixture of low- to high-density single family residences.

NON-NATIVE SPECIES

ANIMALS

Information on the presence of non-native aquatic animal species in these streams is currently unavailable.

PLANTS

Non-native plant species found in the riparian zone of these streams include numerous ornamental species associated with plantings by private and public landowners. Examples include mountain ash (*Sorbus* spp.), blue beech (*Carpinus* spp.), butterfly bush (*Buddleia* spp.), cherry laurel (*Laurocreasus officenalis*), dogwoods (*Cornus* spp.), and non-native rhododendrons (*Rhododendron* spp.). Non-native species of plants more closely associated with riparian and aquatic environments include: Scot's broom (*Cytisus scoparius*), reed canarygrass (*Phalaris arundinacea*) (which is abundant throughout these subbasins), and Himalayan and evergreen blackberries (*Rubus discolor and R. laciniatus*).

HYDROMODIFICATION

THE HILLSIDE DRAINAGES

Minimally detained stormwater in this developed area has caused varying degrees of the stream channel damage. For example, in stream 09.0068A, channel incision of up to two feet was noted in the vicinity of the outfall pipe from SE 293rd Street.

In some reaches, the streambank consists of gabion basket bank armoring, while elsewhere the stream has been diverted through pipes into ornamental fountains.

KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- Historically, these creeks appear to have served as important refugia for anadromous salmonids that reared year round in the Green River basin.

- The impervious area of many of these subbasins is expected to range from 15 to 33 percent in the near future.

- Current and future development has and will likely continue to generate increased stream flows, channel instability problems and instream and riparian habitat degradation.

- Wetlands played an important function in maintaining streamflows in many these small streams. Many of these wetlands have been partly or completely eliminated and the remaining wetlands are continuing to be degraded.

- There is currently only very limited utilization by anadromous salmonids in these streams.
- Known and suspected anthropogenic barriers limit access to spawning and rearing habitat.
- The quality and quantity of gravels in the stream limits spawning success and, to a lesser degree, juvenile rearing habitat.
- Although only limited quantitative information is currently available, it is the professional judgement of the Factors of Decline Subcommittee that flood flows due to increased impervious surfaces effectively preclude successful incubation.

DATA GAPS

- There is no evidence that these streams can support all life stages of anadromous salmonids.
- Fish passage barriers have not been comprehensively assessed for the subbasin.
- Information regarding existing riparian conditions and functions for supporting salmon habitat is limited.
- There is no LWD inventory for the subbasin..
- Aquatic invertebrate populations should be monitored and the cause of lack of diversity and presence should be determined and addressed.

EARLY ACTION RECOMMENDATIONS

A comprehensive baseline habitat survey (including elements that address the above-referenced data gaps) should be initiated to shape a subbasin-wide strategy and rehabilitation objectives. This strategy should be used to direct the type and timing of rehabilitation efforts to maximize resource potential and promote efficient monetary expenditures. It is important that this subbasin strategy is well integrated with the overall WRIA 9 Strategy to recover salmon.

LIST OF TABLES

EH-1: Land Use of the East Hill Tributaries to the Green River

3.6 MIDDLE GREEN RIVER TRIBUTARIES

Physical Description 2
Subbasin 2
Stream Course and Morphology 2
Salmonid Use 3
Factors of Decline 3
Fish Passage 3
Riparian Condition 4
Hydrology 6
Sediment Condition 7
Water Quality 9
Land Use 9
Non-Native Species 10
Hydromodification 10
Floodplain Connectivity 11
Key Findings and Identified Habitat-Limiting Factors 11
Data Gaps 12
Early Action Recommendations 12

3.6 MIDDLE GREEN RIVER TRIBUTARIES

PHYSICAL DESCRIPTION

SUBBASIN

This section includes the following tributary streams to the mainstem Green River upstream of the confluence of Soos Creek (RM 33.65) and downstream from the confluence with Newaukum Creek (RM 40.7):

- Burns Creek (09.0105);
- Crisp Creek (09.0113) (locally referred to as Keta Creek);
- O’Grady Creek (09.0107); and
- Nine other locally named or unnamed tributaries (09.0100 through 09.0110).

These streams are grouped together because of their similar drainage basin size, geomorphic characteristics, flows, geographic location and salmonid resource utilization.

STREAM COURSE AND MORPHOLOGY

Burns Creek (a right-bank tributary to the Green River) has its origins from a spring. It drains much of the east valley floor in this reach and enters the Green River at the upstream end of the Loans Levee (RM 38.0). Burns Creek is fed by three tributaries, all located along the north valley wall. The upstream tributary has its origins as a wall-based spring, while the two downstream tributaries flow from steep-sided ravines. Once Burn Creek enters the valley floor, it flows through old river channels before joining the mainstem Green River.

Crisp Creek enters the Green River at RM 40.1 as a right bank tributary. It drains an area of approximately 5.0 square miles and is approximately 3.0 miles long. The creek has its origins from several groundwater sources and springs (including Keta Creek Springs) which augment the flow of Crisp Creek. The origins of Crisp Creek appear to be a 20-acre, relatively pristine bog at approximately 600 feet in elevation. Crisp Creek moves across a natural plateau before it drops steeply over the topographic break that discerns the plateau from the valley walls of the Green River. The stream becomes slower with a lower gradient when it reaches the alluvial valley floor and then travels roughly parallel to the Green River before entering it. Two lakes important to surface water flow (Horseshoe and Keevies) are located within the subbasin. The Keta Creek Hatchery (one of two Muckleshoot Indian Tribe (MIT) hatcheries) and two adjacent former WDFW rearing ponds are located at approximately RM 1.05 of Crisp Creek.

The mainstem of O’Grady Creek originates from wetlands and is approximately 2.4 RM long, with a single wall-based tributary that contributes an additional mile (total of 3.4 RM). O’Grady Creek (09.0107) joins the Green River through an oxbow (side channel) along the left bank at approximately RM 39. The O'Grady Creek subbasin and drainage basin area includes 1.3 square miles. The creek is best characterized when it is divided into three distinctive reaches or sections:

- An upper headwater reach (approximately 1 mile long) with a low gradient that meanders through plateau farmland;
- A middle reach (approximately 0.8 miles long) that descends from the plateau through a high-gradient, steep-walled ravine to the Green River valley floor; and
- A lower reach (approximately 0.5 mile long) that comprises the alluvial fan.

O'Grady Creek subbasin is impacted by the Osceola Mudflow, a natural geologic feature that originated from a past eruption of Mt. Rainier and is the dominant geologic feature of the plateau. The mudflow deposited a large area of unsorted clay sediments which created a flat, riverine topography combined with significant numbers of depressions. These depressions formed the wetlands and are similar to the features of the Newaukum Creek subbasin (see Hydromodification—Off Channel Habitat, below).

Stream course and morphology information on the several small tributaries mentioned above (09.0098 through 09.0106) was not located or made available during the course of this report.

SALMONID USE

More than 10 miles of stream length of the combined Middle Green River tributaries are accessible to anadromous salmonids.

The known freshwater distribution of anadromous salmonids is depicted in the report Appendix. Chinook, sockeye, coho, pink and chum salmon (along with winter steelhead adults) have been observed spawning in these tributaries (WDFW Spawning Ground Survey database). Burns and Crisp Creeks provide spawning and rearing habitat for coho, chinook, chum and winter steelhead. Coho and chum salmon adults and juveniles utilize O'Grady Creek.

Resident and anadromous cutthroats have been observed throughout the these streams and lakes. Crisp Creek also serves as the water supply for the MIT Keta Creek Hatchery and rearing ponds.

The lower reaches of the primarily smaller, wall-based streams (09.0098 through 09.0106) are utilized for spawning by coho and chum, and rearing by chinook, coho, chum, and winter steelhead.

FACTORS OF DECLINE

FISH PASSAGE

King County is currently conducting a comprehensive investigation of culvert and bridge crossings of county roads in the Green River basin. It is expected that this investigation will produce a database identifying barriers or constrictors of stream channels on King County Roads.

That survey should be completed in late 2000 or early 2001 and does not include city or private roads.

The known barriers to anadromous salmonids are shown in the report Appendix.

CRISP CREEK

The Keta Creek Hatchery (one of two Muckleshoot Indian Tribe (MIT) hatcheries) and two adjacent former WDFW rearing ponds are located at approximately RM 1.05 Crisp Creek. A dam at the facility ponds water upstream and also creates an anadromous barrier. The hatchery rears and releases at both on and off-station locations chum, coho, chinook salmon. Winter steelhead are reared at this facility and released off-station.

O'GRADY CREEK

Within O'Grady Creek there are no known passage barriers for salmonid juveniles in the reach downstream of the culvert and upstream of the confluence.

However, O'Grady Creek chronically overflows its banks during fall and winter at a point about 1,000 feet upstream from the confluence with the Green River. This causes much of the stream to flow in a shallow, sheet-like manner across the remnant pasture. In the past, adult chum and coho and juvenile salmonids have been stranded as the creek drops back into its banks. This reach is currently the recipient of a King County restoration project to construct a more stable channel.

Boehm (1999) noted that during seasonal low-flow periods there was insufficient flow across the alluvial fan for adult salmonids to access O'Grady Creek in the most recent four years (1995-1999). He also noted that "…strandings have occurred...", but no species were identified.

RIPARIAN CONDITION

CRISP CREEK

The upper reaches of Crisp Creek contain deciduous trees, primarily red alder and black cottonwood, with some conifers where the stream traverses through commercial timberlands. There is a sparse, mixed coniferous and deciduous stand of second-growth trees along Crisp Creek just upstream of the Auburn-Black Diamond Road. Downstream of the commercial timberlands, the stream gradient flattens and the riparian area becomes wider and larger with mostly deciduous trees growing from the top of the stream bank to the stream. Downstream of the MIT Keta Creek Hatchery, Crisp Creek flows past several farms and houses and has little functioning riparian habitat (primarily willows), until just prior to its confluence with the Green River. The riparian habitat at the confluence of Crisp Creek and the mainstem Green River is comprised primarily of large cottonwood trees (Kerwin 2000).

O'GRADY CREEK

Native vegetation riparian buffers are lacking within the upper plateau reaches of the O'Grady Creek subbasin. There are sections of willow (*Salix sp.*), ninebark (*Physocarpus capitus*), vine maple (*Acer circinatum*), black cottonwood (*Populus trichocarpa),* and scattered stands of Sitka spruce (*Picea sitchensis*), and western red cedar (*Thuja plicata*).

Historic logging practices harvested the old-growth forest within the ravine in the early 1900s. The riparian zone throughout most of this reach is vegetated with second-growth deciduous forest and shrubs. Boehm (1999) found the mid-section riparian buffer of O'Grady [0–450 meters (0-1320 feet)] to be dominated by willow, red-osier dogwood, red alder and black cottonwood saplings. The overstory vegetation pattern of the upper section of his study area, (2,600-5,600 feet below the ravine above the culvert) was dominated by red alder, big leaf maple, black cottonwood, and bitter cherry (*Prunus emarginata*). There were a few sections of coniferous overstory in the study area and the upper reaches of the wall-based tributary included western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterphylla*), sitka spruce (*Picea sitchensis*), and Douglas fir (*Pseudotsuga menziesii*). Additional upland plants found in the shrub layer include red elderberry (*Sambucus racemosa*), beaked hazelnut (*Corylus cornuta*), and indian plum (*Oemleria cerasiformis*). Sword fern, bleeding heart (*Dicentra formosa*), Pacific waterleaf (*Hydrophyllum tenuipes*), and trillium (*Trillium ovatum*) were the dominant plants found in the understory. In the moist upland areas, and in wet areas, piggy-back plant (*Tolmiea menziesii*), Scouler's corydalis (*Corydalis scouleri*), false lily-of-the-valley (*Maianthemum dilatatum*), current (*Ribes bracteosum*), and salmonberry were all present. Scouler's corydalis, skunk cabbage, water parsley (*Oenanthe sarmentosa*), horsetail, reed canary grass, and scattered cattails (*Typha latifolia*) were identified in sections of the wetland and overflow area adjacent to O'Grady Creek approximately 828 feet-1159 feet downstream of the culvert.

In the lower stream reach, adjacent to the mainstem Green River, there is no development adjacent to the stream buffer other than past clearing and a remnant pasture within the alluvial fan downstream of the access road culvert. Boehm (1999) examined three study reaches in the lower portion of O'Grady Creek, including the wall-based tributary in that area. He found that a riparian coniferous forest overstory was lacking in the stream buffer from the outlet with the Green River side channel upstream 993 meters (3,287 feet). He did note the presence of "patches" of conifers in the upstream reaches of both streams. In the study areas examined by Boehm (1999), the riparian vegetation was is dominated by a young, hardwood forest consisting of young red alder (*Alnus rubra*), larger and older individual black cottonwood *(Populus trichocarpa*) and occasional big-leaf maple (*Acer macrophyllum*). There was also a shrub layer is dominated by willow (*Salix spp*.), red-osier dogwood (*Cornus stolonifera*), vine maple (*Acer circinatum*), Himalayan blackberry (*Rubus discolor*), snowberry (*Symphoricarpos alba*), and salmonberry (*Rubus spectabilis*). There was a sparse herbaceous layer in the wet depressions/small wetlands adjacent to the stream consisting of skunk cabbage (*Lysichitum americanum*), giant horsetail (*Equisetum telmatiea*), reed canarygrass (*Phalaris arundinacea*), and lady fern (*Athyrium filix-femina*).

LARGE WOODY DEBRIS

There have not been any quantitative surveys of LWD abundance in the creeks in this reach. An active program to remove LWD from the Burns, Crisp and O'Grady Creek systems over the past 150 years, combined with the loss of the historic coniferous riparian buffer and associated potential recruitment of large trees/key pieces of wood with rootwads, have impacted stream process formation and morphology, and ultimately salmonid species production and composition.

Crisp Creek

While no quantitative counts of large woody debris were found, there is a limited amount of large, functional woody debris in the channel to buffer changes in sediment and water flow (Malcom 2000).

O'Grady Creek

Within the reach of O'Grady Creek examined by Boehm (1999), there was an almost complete lack of both small and large woody debris (LWD) within both the active channel and the floodway. However there were some areas with lateral and side channel LWD accumulation. Winter high flow events have evidently placed most of the LWD as debris dams, lateral logs or bridges. Most of the debris accumulations were upstream of the access road culvert within the ravine. For the purpose of his study, Boehm defined LWD as being in excess of 10 inches in diameter and 10 feet) long. Using this definition, he found 17 pieces of wood within the study reach of O'Grady Creek that qualified as LWD, and about 3 pieces for the wall-based tributary. Calculating this on a piece-per-distance basis, there are 1.7 pieces/100 meters and 1.4 pieces/100 meters respectively.

Boehm (1999) also examined pool quality formed according to the methodology presented by Platts et al. (1987). This protocol assigns each pool a score ranging from 1 to 5. A pool with a value of 1 has little habitat value for salmonids while a rating of 5 would have superior habitat value for salmonids. In the study area, the average pool quality index (PQI) rating was 2, with an average maximum and residual depth of 0.54 meters (1.8 feet) and 0.41 meters (1.4 feet), respectively. LWD or an LWD/ boulder matrix combination were the responsible pool-forming features.

Therefore, the lack of LWD is a limiting factor in the production of anadromous salmonids in the O'Grady.

HYDROLOGY

CRISP CREEK

At present, increases in peak flows caused by precipitation do not appear to substantially adversely impact Crisp Creek. However, this scenario could easily change if the stream receives more overland flow as a result of increased impervious surfaces and loss of forest cover. This change in hydrology will cause higher and more frequent stormflow peaks and could cause channel instability.

Crisp Creek's existing mean annual flow is fairly low. Based on King County stream flow gage 40D, mean annual flow for the period of water year 1995 through 2000, is approximately 8.8 cfs. The mean annual 1-day minima stream flow is about 2.5 cfs with the lowest stream flow occurring in 1995 (Burkey 2000). If too much water were to be withdrawn or groundwater recharge were to be interrupted, it is likely that the stream could go dry during seasonal low flow periods.

O'GRADY CREEK

The O'Grady system responds quickly to rainfall from seasonal storm events that move through the watershed, generating high-peaked flash flows. Increases in impervious surface areas due to urbanization in combination with changes in historic land use practices (i.e., conversion of coniferous forests to pasture land) and the impermeable Osceola mudflow that covers most of the upper watershed the Enumclaw plateau have collectively created this hydrologic sensitivity and poor hydrologic. The natural impervious layer of the Enumclaw plateau and the lack of LWD in the O'Grady Creek system has created high-velocity conditions with high bedload mobility (see Riparian Condition—Large Woody Debris; and Sediment Condition0).

Peak flows coincide with the winter storm season of November through March. Based on 4 years of data from King County stream gage number 40C (water years 1992 – 1995 inclusive), the annual maxima mean daily flow is just under half of the annual maxima daily maximum. The mean annual flow rate for O'Grady Creek for those 4 years is approximately 1.5 cfs. The annual 1-day minimum flow ranges from 0 - 0.4 cfs. However at low flow, the gaging records may not accurately measure stream flow (Burkey 2000).

The transport of sediments and movement within the lower reaches of the O'Grady Creek system is also high (see Sediment Condition).

Water Rights

The tributaries to the Green River have been closed to additional surface water withdrawals since 1980 (Chapter 173-509 WAC). However, potable water wells that produce less than 5,000 gallons per day do not require a water right. It is not known how many of these wells are present in the subbasin, nor their cumulative impacts on groundwater discharge and stream baseflow to these creek systems.

SEDIMENT CONDITION

Substrate conditions of the creeks within this subbasin have not been thoroughly investigated.

BURNS CREEK

Burns Creek is impacted by sediments originating from landslides in one of its tributaries, locally known as Doll Creek. Doll Creek originates on the plateau approximately 240 feet above the Green River valley. The landslides are located in a section of the creek locally referred to as the Bell Ravine. The Bell Ravine is a young geologic process that is formed by the creek cutting down through softer sediments on its way to the Green River valley floor. Landslides in Bell Ravine are a part of a natural process, but may be exacerbated by historic and current land use practices.

Landslides are present in aerial photographs taken of Doll Creek in 1936 and 1985. However, they are not believed to have caused the sedimentation problems in Burns Creek (Perkins 1999).

During the winters of 1990 and 1995-96, sustained, intense rainstorms caused large landslides that reactivated sediment fans (in 1990) and led to sediment deposition in Burns Creek. Perkins (1999) indicates between 1985 and 1999, between 12,000 and 34,000 cubic yards of sand and gravel probably entered Doll Creek. Between 4,000 to 8,000 cubic yards were deposited in the alluvial fan at the confluence of Doll and Burns creeks.

Perkins (1999) examined sediments in the lower reaches of Burns Creek downstream of the confluence with Doll Creek. This area has an average stream gradient of 0.2 percent (Perkins 1999). She found this reach to be comprised of either sands or silts up to three feet thick. These sediments have reduced pool depths and buried salmonid spawning gravels. Coho and chum salmon continue to spawn in this reach, but their reproductive success is thought to be marginal.

This sediment buildup has largely been responsible for local flooding. The response by local property owners has been to conduct a maintenance dredging program once or twice each year since 1996. However, the landslides are believed to be a natural process and not directly the result of land use activities (Perkins 1999). Typically, permits have allowed up to 49 cubic yards of sediments to be removed during each maintenance dredging. This dredging is supposed to be in the vicinity of residential driveways, but dredge spoils are present on both banks from approximately 250 feet downstream of private property along Burns Creek. During 1997, King County also removed sediments from Burns Creek stream channel below the confluence with Doll Creek in an effort to minimize flooding of the S.E. Green Valley Road.

Williams (1975) noted the presence of only “patchy” gravels in Burns Creek and either gravels were absent or covered at that time.

CRISP CREEK

Crisp Creek is similar to Burns Creek in that the lower reaches are heavily silted and significantly altered where they pass through agricultural lands (primarily pastureland). The creek has its origins from a wetland northwest of Keevies Lake. The hydrology of the creek is dominated by groundwater and baseflow is the main component of the annual hydrograph (MIT, 1993).

The upper reaches of Crisp Creek are relatively stable and capable of accommodating winter stream flows, in part due to limited urban and residential development and the low channel gradient. However, immediately above the MIT Keta Creek Hatchery, Crisp Creek flows through a confined area that is surrounded by unstable landforms. These landforms are a source of fine sediment and landslides when disturbed (MIT, 1994). Crisp Creek has the potential to become degraded through aggradation and erosion processes due to peak flows.

O’GRADY CREEK

Excessive scour and deposition has been documented by Bill Priest (Bill Priest 1999 as contained in Boehm 1999). The intensity of scour and sediment movement is severely a limiting factor for salmonid production in the O’Grady Creek system. This would be adversely impacting the survival rate of cutthroat, coho and chum eggs during incubation and coho and steelhead during rearing.

Boehm (1999) found that winter flood-flows were responsible for substantial sediment loading and bed movement within the study reach of O'Grady Creek. Within the reach examined, he found that substrates were moderately imbedded within a fine-grain matrix. The area poorest in spawning gravels was the 1,225 feet – 2,259 feet reach of channel with a lower stream gradient and a sand dominated substrate. The wall-based tributary had a substrate with less sand present and was dominated by large gravel (25 mm to 100 mm) (40%), cobble (100mm-256mm) (30%), small gravel (20%) (<25mm), and sand (10%). There are also a few cobbles present within the stream channel.

WATER QUALITY

Burns, Crisp and O'Grady creeks are all classified as a Class A waters (WAC 173-201A).

Burns and O'Grady Creeks currently meet all numeric water quality standards for all monitored chemical constituents, including fecal coliforms, water temperature and dissolved oxygen.

Crisp Creek currently meets all numeric water quality standards for a variety of chemical constituents, including water temperature and dissolved oxygen. However, like many other streams in the Green River basin, Crisp Creek does not currently meet water quality standards for fecal coliform, and appears on the Environmental Protection Agency 1998 303(d) list (WSDOE 2000) for exceeding the upper criteria in samples collected between 1991 and 1997.

Water quality information on several other tributary streams in this reach was not available.

Water quality in Burns, Crisp and O'Grady Creeks is not believed to be a limiting factor at this time.

LAND USE

BURNS CREEK

Aerial photographs from 1936 of the Burns Creek subbasin show an immature forest, probably the result of logging activities in the early part of the 20th century. Numerous old landslide bowls are also present in these photographs. These landslides may be the result of reduced root strength of immature trees and/or more winter storms with high and intense precipitation patterns.

CRISP CREEK

The historic old-growth forest around Crisp Creek was also logged sometime near the beginning of the 20th Century. There are some remnant old-growth Sitka spruce and Western red cedar trees widely scattered throughout the subbasin.

Currently, approximately 69 percent of the watershed upstream of approximately RM 11 is managed for commercial timber production (Malcom 2000). Beginning in 1991, commercial logging activities harvested the majority of the second-growth timber on the commercial forest land tracts. Within the Crisp Creek drainage area there are at least six concentrated areas of residential development with densities of 1 house per acre or less. The remaining land use is considered rural residential with lot sizes of 1 to 10 acre. The residential sites vary in vegetative conditions from clear-cut to pastureland to small private woodlots with a single residential house.

O'GRADY CREEK

O'Grady Creek has experienced significant and substantial changes since historic times (prior to 1860). Virtually all of the original pre-settlement wetland forests of Sitka spruce and western red cedar, and upland forests within the subbasin have been logged (in some cases twice) and then cleared. Following clearing, land use on the plateau was dominated by hay and straw production, and dairy farms (King Co. Basin Recon. 1990). Currently, the subbasin is predominantly rural in character, but under increasing pressures to convert to new single-family residences on smaller parcels, and a breakup of the large-acreage pasture into "hobby" farms. Currently, there are several large horse stables and horse breeding farms on the plateau.

NON-NATIVE SPECIES

ANIMALS

No information on non-native fish species was located during the course of this investigation.

PLANTS

Reed canarygrass (*Phalaris arundinacea*) is abundant throughout this subbasin. Himalayan blackberry (*Rubus discolor)* is present in O'Grady Creek subbasin.

HYDROMODIFICATION

O'GRADY CREEK

In 1984, a land owner channelized the lower 600 meters (1980 feet) of O'Grady Creek. This removed all of the meanders (and LWD) from the historic channel to force stream flows into the newly excavated and straightened channel. This lower section has experienced the greatest habitat damage from property owners. This damage limits natural production of salmonids.

Local channelization is extensive in the lower reaches of Burns and Crisp Creeks where they traverse across the valley floor through agricultural lands.

SOUTH FORK BURNS CREEK

The South Fork of Burns Creek has its origins in a wetland that historically received flow from Crisp Creek during floods. Prior to the construction and operation of Howard Hanson Dam in 1962, the South Fork of Burns Creek also received flood waters from the mainstem Green River. These flood waters are believed to have flushed the fine sediments from the South Fork of Burns Creek, leaving behind spawning gravels that were capable of supporting spawning salmon.

After the dam was constructed in 1962, flood flows from the mainstem Green River no longer occurred in the upper reaches of Burns Creek. Williams (1975) noted that in the previous 15 years, stream habitat degradation had occurred due to "…heavy silting, extensive aquatic weed growths, and reduced flows." He attributed the observed siltation problems to land use practices and illegal hydraulic projects of that time period.

In addition to the flow changes believed to be caused by the building and operations of Howard Hanson Dam, changes in mainstem Green River channel location is also thought to contribute to increased siltation of this area in Burns Creek. A comparison of aerial photographs between 1936 and 1958 indicates that the Green River abandoned a meander bend upstream of Burns Creek during this time period. As a result, this channel migration moved the mainstem river away from Burns Creek, and contributed to a reduction of flood flows from the mainstem Green River into Burns Creek.

OFF CHANNEL HABITAT

Crisp Creek

The upper portion of the Crisp Creek has numerous adjacent wetlands that mostly remain connected to the stream.

O'Grady Creek

There are still large wetlands present in the upper reaches of this subbasin. The largest include O'Grady Creek No. 85b, 94b, 5 (51 acres), and O'Grady Creek No. 88b (King Co. Wetlands Inventory 1990). However, most of the plateau wetlands have either been cleared, ditched, filled and/or are extensively grazed by livestock.

FLOODPLAIN CONNECTIVITY

As previously mentioned, O'Grady Creek originates from a group of wetlands and then descend westerly into a series of ditched streams that coalesce at the eastern edge of the Osceola flow area before entering a steep-walled, high-gradient ravine. The grazed wetlands are often inundated with water during the winter. This is evidence of highly compacted soils and poor permeability that is a characteristic of the Osceola mudflow. The poor permeability of the Osceola flow area and the compacted soil caused by extensive grazing generates a combination of conditions that favor a severe rapid runoff pattern during rain and rain-on-snow storm events.

KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- There is a general lack of habitat information for this subbasin.
- The subbasin is undergoing a rapid conversion from forest and rural to a more urbanized environment.
- The riparian buffer in this subbasin is insufficient and is limiting natural salmonid production.
- There is a lack of LWD throughout the streams in this subbasin.

- Summer low flows limit available rearing production for species of salmonids that require over-summer residency.

- High winter flows limit the reproductive success of coho and chum salmon because of scour and bedload movement and coho and steelhead because of lack of refugia.

- Channelization of the lower reach of O'Grady Creek has eliminated stream channel complexity and limits natural production of salmonids.

- Sediments in the lower reaches of Burns, Crisp, and O'Grady creeks are believed to be limiting the success of egg incubation of anadromous salmonids in this reach.

DATA GAPS

- Information on several small tributaries (09.0098 through 09.0108) was not located or made available during the course of this investigation.

- Baseline habitat information is lacking for all or portions of the creeks in this reach.

- The impact level of non-native and invasive aquatic plants on naturally producing salmonids is not well understood..

- Use and importance of these streams as overwintering refuge habitat for juvenile salmonids from high mainstem flows is not fully known.

- The amount and type of LWD is not known. .

- The amount of loss of streambed channel and complexity after channel relocation is not known.

- The quality of the sediments in the lower reaches of Burns, Crisp, and O'Grady creeks are not fully known .

EARLY ACTION RECOMMENDATIONS

- Conduct baseline habitat inventory surveys

- Comprehensive barrier surveys need to be initiated in this subbasin.

- Comprehensive base line riparian habitat and bank condition surveys should be initiated.

- An inventory of LWD should be initiated.

- Historic channel location information needed.

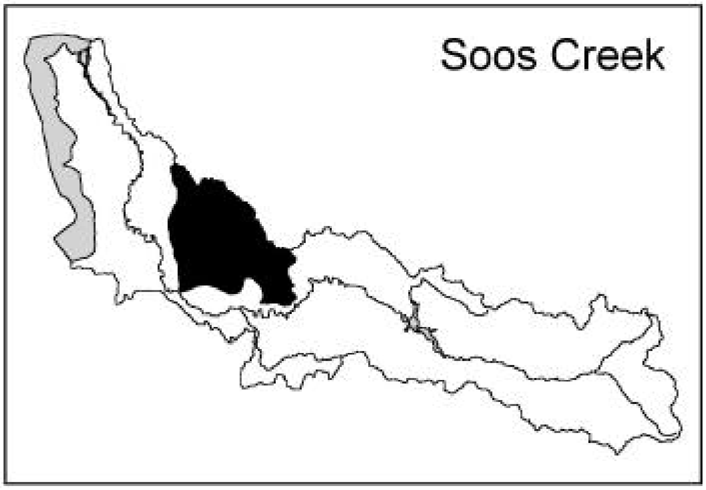
3.7 SOOS CREEK SUBBASIN

Physical Description 2
- Subbasin 2
- Stream Course and Morphology 2
- Salmonid Use 3

Factors of Decline 4
- Fish Passage 4
- Riparian Condition 5
- Hydrology 5
- Sediment Condition 7
- Water Quality 8
- Land Use 8
- Non-Native Species 9
- Hydromodification 10

Key Findings and Identified Habitat-limiting Factors 12
Data Gaps 13
Early Action Recommendations 13

3.7 SOOS CREEK SUBBASIN



PHYSICAL DESCRIPTION

SUBBASIN

The Soos Creek subbasin is best defined as an area in south King County, north and east of the Green River and southeast of the City of Renton. The Soos Creek subbasin consists of the mainstem Big Soos Creek (09.0072) with approximately 25 identified tributary streams totaling over 60 lineal miles. There are three major tributaries:

- Covington (09.0083);
- Jenkins (09.0087); and
- Soosette (09.0073, also known as the West Branch of Soos Creek).

STREAM COURSE AND MORPHOLOGY

The subbasin drains an area of approximately 44,800 acres (70 square miles). The basin is comprised of three distinct physical settings (Figure HM-2 in the Hydromodifications Appendix).

The headwaters of Soos Creek originate on a rolling glacial outwash plain. The channel is unconfined, has a gradient of less than 0.1 percent, and flows through extensive wetland complexes. Stream flows are generally small, with little erosive energy, and the channel is described as alternating between "sections of good gravel and sections of swampy channel splits with mud bottoms" (Williams 1975), characteristic of a Palustrine channel type.

At approximately RM 4.75, Soos Creek enters a narrow, steep-sided ravine containing long riffles with pools. The channel becomes a Moderate Gradient Mixed Control type, with a gradient of approximately 1.4 percent. Major lakes in this system include Lake Youngs (a domestic water supply for the City of Seattle), Shadow Lake, Lake Meridian, Lake Sawyer, Morton, Pipe/Lucerne and Wilderness Lakes. These lakes have a combined surface acreage of approximately 1,370 surface acres (Wolcott 1973).

Downstream of RM 2, the channel gradient decreases to around 0.5 percent, and Soos Creek becomes a Floodplain channel type that occupies a steep-sided valley.

Pool-to-riffle ratios differ considerably between the upper and lower reaches of Soos, Little Soos, Covington, Jenkins and Soosette Creeks (Table Soos-1). Ideal pool-to-riffle ratios should have approximately equal frequencies of each element.

Table Soos-1. Pool - to - Riffle Ratios of Streams in the Soos Creek Subbasin.

Stream Name	Upper Reaches	Lower Reaches
Little Soos Creek	20:80	50:50
Big Soos Creek	30:70	20:80
Covington Creek	90:10	5:95
Jenkins Creek	90:10	10:90

Source: King County 1990.

SALMONID USE

The known freshwater distribution of anadromous salmonids is depicted in the report Appendix.

The headwaters of Soos Creek arise on a rolling glacial outwash plain. In such landforms, streams often originate in wetlands, and exhibit low-gradient, palustrine-type channels until flows become sufficient to regularly transport coarse sediment. The gradient of mainstem Soos Creek is 1 to 2 percent throughout its course (Cutler 2000), and no natural barrier falls or cascades have been identified (Williams et al.1975). The upstream extent of spawning by anadromous fish, is not known, but is presumed to be limited by flow, substrate or in-stream vegetation and not gradient. Juvenile fish are expected to use the entire length of available channel and associated wetlands for rearing.

Chinook, sockeye, coho, pink and chum salmon (along with winter steelhead adults) have been observed spawning in the Soos Creek subbasin (WDFW Spawning Ground Survey database).

A single bull trout was reported captured at the Soos Creek State Fish Hatchery (SFH) in 1956 (Beak Consultants 1996). Resident and anadromous cutthroats have been observed throughout the streams and lakes.

SFH captures adult chinook and coho for on- and off-station releases, with an annual production of approximately 3.2 million fall chinook sub-yearlings and 600,000 coho yearlings.

FACTORS OF DECLINE

FISH PASSAGE

Known barriers to anadromous salmonids are shown in the report Appendix.

SOOS CREEK SALMON HATCHERY

The Soos Creek Salmon Hatchery (located at RM 0.7) was constructed in 1901 and has been in continuous operation since that time. Between 1902 and 1924, portable double racks were installed in the mainstem Green River at the mouth of Soos Creek to provide eggs for the hatchery, since chinook salmon did not enter Soos Creek at that time (Becker 1967). Annual installation of the portable weirs on the mainstem was discontinued in 1924, as large numbers of chinook had begun to return to Soos Creek by that time (Becker 1967).

The existing hatchery rack consists of two removable weirs located approximately 100 feet apart that are used to create a holding pond (Figure Pass-15). The weirs are generally installed around August 15, when the first chinook begin to arrive , and removed around the 3rd week of November when coho egg take requirements have been met (Chamblin 2000). A sheet-pile dam (used to divert water into the hatchery) is located just upstream. The diversion dam is equipped with a fish ladder (Figure Pass-16).

The hatchery rack acts as a barrier when it is in place. However, large storm events or other unforeseen occurrences may wash out the weirs or allow fish to pass the structure. For example, during a storm in September 1997, over 8,000 chinook were able to leave the hatchery and move upstream into Soos Creek when the weir failed (Finney 2000). Beavers have also been responsible for causing holes that allow adult salmonids to migrate upstream (Kerwin 2000). When the hatchery weirs are not in place, anadromous salmonids can move freely upstream. The hatchery does not interfere with the downstream movement of juvenile fish.

CULVERTS

Although a number of barriers associated with road crossings have been identified on tributary streams (Figure Pass-4 located in the Fish Passage Appendix), no existing barriers to upstream migration in mainstem Soos Creek have been identified.

King County is currently conducting a comprehensive Green River Basin investigation of culvert and bridge crossings of county roads. It is expected that this investigation will lead to a database that identifies culverts and other structures that block or constrict stream channels. That survey should be completed in late 2000 or early 2001.

LOW INSTREAM FLOWS

Low flows reportedly reduce the ability of chinook to reach the Soos Creek hatchery (WDFW and WWTT 1994), and thus influence the amount of natural spawning downstream of the hatchery as well as the number of chinook that may be released upstream of the hatchery rack. The specific location of low flow concerns was not identified, and could include low flow concerns in the mainstem (WDFW and WWTT 1994). However, a declining trend in the average

7-day low flows just upstream of the hatchery has been identified (Culhane 1995), and is discussed in more detail in this chapter(see Hydrology). Declining flows support the hypothesized low flow concerns in Soos Creek.

WATER TEMPERATURE

There are no segments of mainstem Soos Creek listed on the 1998 Washington State 303(d) list for temperature concerns (WDOE 1998), thus temperature is currently assumed not to limit the upstream migration of adult salmonids in Soos Creek. However, temperature concerns that represent potential passage barriers have been identified on a number of tributaries (Figure Pass-4 in the Fish Passage Appendix). In addition, DO levels less than 8 mg/l have been recorded near RM 10. Low DO levels could cause salmonids to avoid entering this section of the stream, thereby delaying upstream migration.

RIPARIAN CONDITION

No data was obtained during the course of this investigation that provided additional information concerning riparian types, canopy, depth, seral stage or composition.

LARGE WOODY DEBRIS

There have not been any quantitative surveys of LWD abundance.

King County (1990) reported moderate, but not sufficient, amounts of LWD to all but the steepest reaches of Soos Creek. That same document did not supply additional qualitative information on other tributaries in this subbasin.Typically, as structure (i.e.: LWD) is eliminated, the ratio shifts towards riffle-dominated reach.

HYDROLOGY

The Soos Creek subbasin is changing from forested/rural to one heavy urbanized (particularly in the western areas). The subbasin has an extensive system of interacting lakes, wetlands and infiltrating soils that collectively attenuate peak stream flows. In the 1980s, Soos Creek discharged about 8-10 cfs during the summer (Metro, 1988) 400 cfs during one-year event high flows (King County , 1990) to the Green River. The Soos Creek Basin Plan provides a detailed subcatchment peak flow tables and maps for various future and existing conditions HSPF modeling.

Existing flow-related problems are found in the upper stream reaches that undergo natural and anthropogenic low stream flows. In 1990, it was predicted that stream flows would increase by an average factor of 1.8 under build-out conditions. However, some areas were expected to have stream flows increase 3.5 times the 1985 levels (King County 1990). These higher flow increases should be in areas that had highly infiltratable soils that are converted to urban areas with impervious surfaces.

WATER RIGHTS

The majority of water rights issued by the Washington Department of Ecology (WDOE) in the Soos Creek subbasin are for groundwater. The City of Kent, the Covington Water District, and King County Water District #111 are the largest consumers of water in the subbasin. Water rights and water claims are shown in table Soos-2.

Table Soos-2. Big Soos Creek Subbasin Water Rights and Claims.

Source	Qi* (cfs)	Qa** (acre-feet)	Irrigated Acres	Total Number of Rights (R) or Claims (C)
Ground	40.8	19,297	369	99 (R)
Surface	6.1	891	103	89 (R)
Ground	43.3	3.194	1,118	1,374 (C)
Surface	21.2	357	309	296 (C)
Total Ground	84.1	22,491	1,487	1,473
Total Surface	27.3	1,248	412	385

* Qi = Allocated instantaneous water quantity.
** Qa = Annual water quantity.
Source: Culhane 1995.

The usable period of record for streamflow data for the Big Soos Creek subbasin extends from 1967 to 1995. During this period, the amount of ground water allocated (Qi) increased from 5.3 cfs to 40.8 cfs and the annual quantity (Qa) increased from 1,412 acre-feet to 19,297. In 1995, there were 30 applications for water rights for ground water in the Soos Creek subbasin. These applications totaled 40.9 cfs. This is an almost equal amount to that allocated.

The tributaries to the Green River are closed to additional surface water withdrawals since 1980 (Chapter 173-509 WAC). However, declining trends in the average 7-day low flows have been detected in Soos Creek for all years between 1968 to 1993 (Culhane 1995). The likely causes for these instream flow declines includes a combination of decreased precipitation 1993 (Culhane 1995), increases in the percentage of impervious surfaces associated with urbanization, and increased groundwater withdrawal. Potable water wells that produce less than 5,000 gallons per day do not require a water right. It is not known how many of these wells are present in the subbasin and what might cumulative impacts might be. However, it is not entirely clear if this is a long-term trend or just part of a cycle; further data would be useful.

Information in the Ground Water Management Plan (SKCGWAC 1989) and studies conducted by the USGS, ground water withdrawals from the Covington Upland have adversely impacted streamflow in Soos Creek.

The increase in percentage of impervious surfaces in the basin mentioned previously have contributed to decreases in summertime low flows. Increases in winter stormwater flows have been observed (King County 1990) and the King County Surface Water Management Division estimated a three-fold increase in impervious area from 1985 to build-out conditions.

The mean annual streamflow in Soos Creek decreased about 14 percent and the low mean monthly flow decreased about 33 percent during the time period from 1967 to 1992. Precipitation as measured at Palmer decreased only 5 percent during that same period. In the Newaukum Creek subbasin, the mean annual flow decreased 20 percent, the low mean monthly flow decreased about 24 percent and precipitation at Palmer decreased 16 percent from 1953 to

1992. A comparison of this data indicates that while annual streamflow declines were similar between the two basins, the low mean summer monthly flows in the more urbanized Soos Creek subbasin were significantly greater. The declines cannot be attributed to decreases in precipitation alone, but more likely a combination of ground water removal, increases in the percentage of impervious surfaces and decreases in precipitation 1993 (Culhane 1995).

Culhane (1995) concluded that additional groundwater removal from the Soos Creek subbasin upper three or four aquifers would likely contribute to an additional reduction of surface flows.

The amount of water actually used has not been compared against the allocated water rights and water claims in the basin. However, as previously mentioned, the amount of water allocated has risen. Carlson (1994) did a comparison of potential safe water yield within the Soos Creek subbasin. It was the conclusion of this study that the hypothetical ground water yield of the basin is less than the quantity of water already allocated through exempt well water withdrawals and water rights. When water claims are factored into this analysis, the difference is increased even more significantly.

SEDIMENT CONDITION

Erosion and sediment problems were identified in the Soos Creek Basin Plan (King County 1990). That document indicated that while areas of significant bank erosion would expand only marginally, they would likely increase in intensity. Further, the rates of bedload material transported by increased flows and enlarged stream channels will increase several fold. This will increase the magnitude of sedimentation problems where the transported material settles out. Finally, because of uncertainties in the analysis, it is believed that there is an underestimation of actual future sediment movement. Erosion problems (including associated sedimentation and flooding issues) were also identified in Soos Creek Basin Annual Reports (King County 1993, King County 1994).

Investigation within the Soos Creek subbasin (King County 1990) identified six sites with erosion problems, four sites with debris and related erosion problems, and five sites with sedimentation-related problems. In the upper reaches of Soos Creek, sedimentation was identified as a problem between RM 7.2 to 10.4 (King County 1990). In the lower reaches of Soos Creek, sedimentation was identified as a problem in the vicinity of the Green River SFH (RM 0.8). Bank failures and bank erosion was identified as problems in Soos Creek between Jenkins and Covington Creeks, at RM 4.6 and, in the lower 0.6 miles of Covington Creek.

Erosion and sediment problems were also identified in the 1992/93 and 1994 Soos Creek Basin Annual Reports (King County 1993, King County 1994).

In January 1990, Soosette Creek experienced a dam break flood at about RM 1.0 when a gravel pit road culvert became plugged by a cottonwood during a storm event. An estimated 30,000 cubic yards of fill from the road crossing scoured the stream bed and delivered much of the sediment to Soos Creek, about 0.5 mile upstream of the SFH.

Gravels within this subbasin have not been investigated but also have not been identified as a limiting factor. None of the published literature (Williams et al. 1975; Goldstein 1982; King County 1989)on Soos Creek describing fish habitat and environmental conditions contains specific information on the extent of gravel bars in mainstem Soos Creek. King County (1990) found spawning gravels "dispersed" and occurring as patches rather than extensive beds. In that same document it was noted that Little Soos and Soosette Creeks had patches of gravels with smaller particle size throughout the upper reaches of these creeks. These gravels were believed to be both consolidated and unconsolidated, the former condition probably the result of low stream gradients and streambank erosion immediately upstream. Substrate in the floodplain channel segment was described as predominantly gravel (70-80 percent), and "remarkably few areas of problematic erosion or sedimentation were identified" (King County 1989). Aerial photograph coverage of Soos Creek was 1:12,000 scale or larger, and the channel was generally obscured by vegetation, thus no information on either the historic or current extent of gravel bars is available.

Gravels in Covington and Jenkins Creeks tended to be "clean and unconsolidated" but still patchy (King County 1990).

WATER QUALITY

Although no direct pre-development data was found as a part of this report, it is assumed that Soos Creek water quality was historically excellent for salmonids due to the large acreage of headwater wetlands and lakes. This historic wetland /lake complex allows for natural filtration and ground water adsorption keeping flows clean, cool and steady (qualities most likely led to the siting of the SFH near the mouth of the system in 1902).

The Soos Creek Basin Plan (King County, 1990) notes that localized water quality degradation has been observed, including high levels of fecal coliforms in Little Soos Creek and high nutrient levels in the lakes. Non-point pollution of these types are expected to become an increasing threat to fish habitat ands the subbasin develops.

Water quality existing conditions, trends and data gaps for this subbasin is covered in detail in The Water Quality Chapter (Part II, Chapter 1.2) of this report. This chapter notes the recent chemical and biological (B-IBI) monitoring efforts within the subbasin.

Prych (1995) sampled streambed sediments for the presence of metals. Seven streambed samples were collected from three sites. Two sites were in Big Soos Creek (one each upstream and downstream of the confluence with Little Soos Creek), and the third site was in Little Soos Creek. Streamwater samples were also collected at the time of the streambed samples were collected. The concentrations of metals in the streambed sediments were typical of or slightly higher than those in soils from the same subbasins. Cadmium, copper, mercury, manganese, lead, arsenic, antimony, selenium and zinc had maximum observed concentrations in streambed sediments approximately twice as high as terrestrial soil samples (Prych 1995). None of the levels were high enough by themselves to be a limiting factor to fish production.

LAND USE

Land within in this subbasin been converted from old-growth forest to commercial timber production, then to agricultural uses, and now to hobby farms and urban uses and has had significant and adverse effects.

In the Soos Creek subbasin, riparian and instream habitat contributes to the stream diversity and complexity. King County (1987) estimated the riparian forest in the Soos Creek subbasin (table Soos-3.)

Table Soos-3. Riparian Forest Cover in the Soos Creek Subbasin.			
Creek Name	**Total Length Surveyed (miles)**	**Forested Length* (miles)**	**Percent**
Soos Creek	14.2	8.9	63
Little Soos Creek	4.5	2.1	47
Soosette Creek	5.1	3.0	59
Covington Creek	11.3	8.7	77
Jenkins Creek	6.0	3.7	62
Cranmar Creek	3.8	3.4	90
* Forested is defined as having >51 percent upper canopy cover in an area of undisturbed natural vegetation.			

The northern and western portions of the Soos Creek and Big Soos Creek subbasins exhibit the highest density of urban subdivisions; commercial retail centers, and scattered single-family residences. The land along the borders with Kent and Renton (along the Kent-Kangley Road) are the most urbanized. The effective impervious area of Soosette Creek subbasin had reached 8.5 percent by 1985.

Elsewhere in the subbasin, the land is predominantly rural but under increasing pressure of urbanization. The cities of Black Diamond, Covington and Maple Valley are all within the Urban Growth boundaries (UGB) of the Growth Management Act (GMA) as adopted by King County Ordinance 11575 in August 1994 (Appendix C, Map 1). The UGB is a 20-year growth and development line.

The entire subbasin is currently one of the most rapidly developing in the county. As such, these lands are expected to see increased urbanization and the demands on habitats. It should be expected that adverse impacts would increase, especially in those areas inside the UGB. The Soos Creek Basin Plan (King County, 1990) predicted that under future conditions, the flood peaks with a reoccurrence interval of two years would increase up to 3.5 times with an average of 1.8 times over 1985 land use.

NON-NATIVE SPECIES

ANIMALS

Several non-native fish species (primarily warmwater species) are known to be present in the subbasin lakes (table Soos-4). It is not known what adverse impacts these fish have on salmonid populations in this subbasin. However, small- and large-mouth bass and yellow perch are pisceverous and it should be expected that salmonids will make up a portion of their prey.

Table Soos-4. Non-native Fish Species Present in Soos Creek Subbasin.	
Lake/Creek Name	**Fish Species Present**
Meridian Lake	LMB, SMB, PS, YP, BBH
Lake Sawyer	LMB, SMB, BC, YP, BBH
Shadow Lake	LMB, BC, PS, YP
Soosette Creek[1]	BC
Jenkins Creek[1]	PS, C
Unnamed tributary 0089[1]	PS
Unnamed tributary 0090[1]	PS, SMB, BC
Soos Creek[2]	BC, LMB
C = Catfish BBH = Brown Bullhead BC = Black Crappie LMB = Large-Mouth Bass 1 Source: Nelson 2000. 2 Source: Wilson 1999.	PS = Pumpkinseed SMB = Small-Mouth Bass YP= Yellow Perch

PLANTS

Reed canarygrass (*Phalaris arundinacea*) is abundant throughout this subbasin. King County conducted a mapping project to assess the existing and potential threats of invasive, non-native aquatic plants in King County Lakes during 1994 and 1995. That report, published in 1996 (Walton 1996) examined lakes Lucerne/Pipe, Meridian, Morton, Sawyer, Shadow, Shady, and Wilderness in this subbasin and found Eurasian watermilfoil (*Myriophyllum spicatum*) in Lucerne/Pipe, Meridian, Sawyer, Shadow, Shady and Wilderness lakes. Hydrilla (*Hydrilla verticillata*) was identified in Lucerne/Pipe lakes during the 1994 survey. At that time, this identification was the only known infestation in the Pacific Northwest and represented the northern-most occurrence of the plant in North America. Eradication efforts, while successful in reducing total biomass, have not fully eliminated this non-native from these lakes. Purple loosestrife (*Lythrum salicaria*) was identified in Lucerne/Pipe and Meridian lakes.

The survey was not inclusive of all the lakes and ponds in the subbasin. It is not clear what adverse impacts these non-native plant species have on salmonids in this subbasin.

HYDROMODIFICATION

The Soos Creek Basin Plan indicated that channelization has occurred since the early 1900s in the upper Soos Creek system (King County 1989). However, no specific information on the extent and location of bank protection structures was located. No levees maintained by King County or the USACE appear in the GIS database.

Local channelization has occurred in streams in the upper plateau since the early 1900's. No quantitative data has been collected that shows the loss of stream habitat in this subbasin. The result has been the overall reduction of channel complexity, reduction of diversity and abundance of aquatic organisms (King County 1989).

OFF CHANNEL HABITAT

None of the published literature on Soos Creek describes off-channel habitat either qualitatively or quantitatively (Williams et al. 1975; Goldstein 1982; King County 1989). Available aerial photograph coverage of Soos Creek is 1:12000 scale or larger, and except for the lower reaches, the channel was generally obscured by vegetation, thus no information is currently available to assess either the historic or existing extent or condition of off-channel habitat.

Within the floodplain, the Soos Creek subbasin has one of the largest wetland areas in the Green River basin. Wetland complexes are common throughout the upper plateau of Soos Creek and include open-water, scrub-shrub, forested, emergent marsh, wet meadow and bog wetlands. Wetland surveys conducted by King County (King County 1986, 1987a, 1987b) listed over 225 individual wetlands in the Soos Creek subbasin. These wetlands covered approximately 2,076 acres (4.8 percent of the land area in the subbasin). When combined with the lakes in the system over 3,436 acres of the subbasin area are covered with water (7.7 percent of the land in the subbasin).

There has been a trend of filling and draining of wetlands to create agricultural lands, mine peat and create building sites. A comparison of aerial photographs from 1936 to 1995 showed extensive draining and/or filing of wetlands. The loss of wetlands appeared to peak in the mid to late 1960s, when approximately 800 acres disappeared in the upper plateau area of Soos Creek (King County 1990).

The draining and filling of wetlands is still occurring despite regulatory protection (King County 1990). Edge encroachment is also another threat, particularly to the larger wetlands. The cumulative effect of the long-term historic loss is difficult to quantify, but is known to adversely impact groundwater recharge and create greater magnitude and duration flood events.

FLOODPLAIN CONNECTIVITY

Outside of the plateau area (RM 5.0), streams within this subbasin have not had significant modifications to their historic floodplains. There are no identified out-of-subbasin water diversions or regional flood control facilities present. However, Lake Youngs acts as a reservoir for water diverted from the Cedar River and does supply some base flow to Little Soos Creek (Nelson 2000). Immediately downstream of Lake Wilderness, water from Jenkins Creek is pumped to irrigate a golf course and the creek is often dry (King County 1990). Most of the stream channels are formed near their historic channels with only limited changes in the vicinity of road crossings.

The lower 2.5 miles of Soos Creek downstream of the confluence with Covington Creek has typical floodplain geomorpholgy. The channel in this segment is 30 to 40 feet wide (King County 1989) and occupies an alluvial valley that is approximately 500 to 800 feet wide. However, there is channel constriction, due to bank hardening, to protect roads, residential and hatchery development throughout this reach. No information was located describing the current or historic extent of the floodplain in lower Soos Creek, and it is unknown whether bank armoring or disconnection of off-channel habitats have influenced off-channel habitat connectivity. The increased flashiness of the flow regime (Section 5.1.1) has most likely increased the frequency at which floodplain surfaces are inundated, but reduced the duration of time that water is present, thus reducing floodplain recharge. Agriculture and rural development are also hypothesized to have impaired floodplain function in portions of this segment, but the extent of these impacts are unknown at this time.

Flood plains in most parts of the system are predicted to widen, some by more than twice their current width, due to increases in peak stream flows from eventual basin build-out (King County 1990).

KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- There is a general lack of habitat information for this subbasin, especially since the mid 1980s.

- The subbasin is undergoing a rapid transition from forest and rural to urbanization, resulting in a disturbed hydrological regime that leads to salmon habitat degradation.

- Summer low flow discharges are decreasing, which limits available rearing production for species of salmonids that require over-summer residency.

- Due to the King County Basin Plan and other efforts, this subbasin is the best studied of any downstream of Howard Hanson Dam. The existing monitoring and modeling information may make this an ideal basin to direct future studies, especially in the areas of land use and associated impacts upon salmonids (i.e., an indicator subbasin).

- The hatchery rack operation near the mouth of the subbasin has disturbed the natural migration patterns of all salmonids in the subbasin. Hatchery strays (chinook and coho) into the subbasin may be interfering with native subbasin fish spawning success.

- Future water quality and sedimentation impacts from increasing urbanization in the subbasin could threaten hatchery success.

- Although no quantifiable information was available, it was the professional judgement of Technical Advisory Group (TAG) members that the riparian buffer in this subbasin was insufficient. This is in at least partly due to historic land use practices.

- There is a lack of LWD throughout the streams in this subbasin.

- Although limited information was available, it was the professional judgement of the TAG that the increased frequency of flood flows attributed to increased impervious surfaces has been at least partially responsible for degrading salmon habitat through channel incision and excessive sedimentation. These degradations limit successful incubation by scouring and smothering redds and limit rearing by reducing channel complexity.

DATA GAPS

- Little data is available on hydromodifications or habitat in Soos Creek.
- Water quality (particularly during stormwater events) and potential adverse impacts to salmonids are unknown.
- Actual, instantaneous water use within the basin is not known.
- While there is insufficient data to determine if adequate gravel is present and of suitable quality for successful spawning, the available data does indicate that this is a concern that requires additional investigation.

EARLY ACTION RECOMMENDATIONS

- Comprehensive barrier surveys need to be completed in this subbasin.
- Comprehensive base-line habitat surveys should be initiated. These surveys should at a minimum include an inventory of LWD, riparian habitats present, quality and quantity of spawning gravels, quality and quantity of pool, an evaluation of streambank stability and associated mass wasting and erosion/sedimentation problems.
- The loss of stream channel due to channelization should be quantified.
- A flow analysis examining the impacts of seasonal high flow peaks and durations on salmonid production should be initiated.
- A water use and water level monitoring program should be established.
- Additional water flow data should be gathered to provide more certainty about long-term flow trends in this subbasin.

LIST OF TABLES

Table Soos-1. Pool - to - Riffle Ratios of Streams in the Soos Creek Subbasin.

Table Soos-2. Big Soos Creek Subbasin Water Rights and Claims.

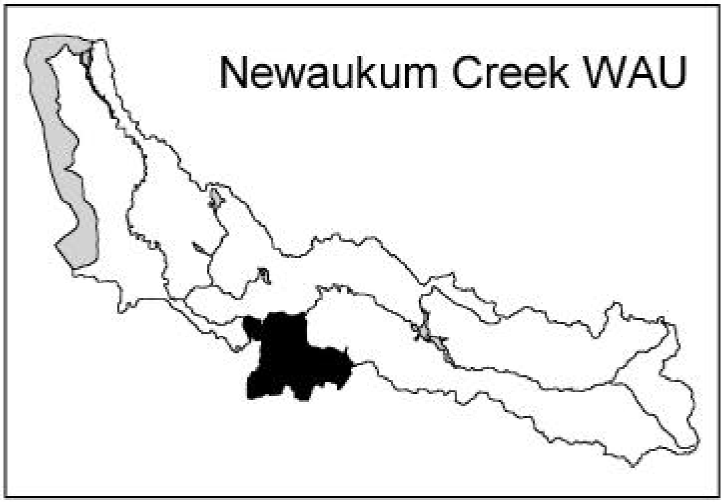
Table Soos-3. Riparian Forest Cover in the Soos Creek Subbasin.

Table Soos-4. Non-native Fish Species Present in Soos Creek Subbasin.

3.8 NEWAUKUM CREEK SUBBASIN

Physical Description 2
  Subbasin 2
  Stream Course and Morphology 2
  Salmonid Use 3
Factors of Decline 4
  Fish Passage 4
  Riparian Condition 4
  Hydrology 5
  Sediment Condition 7
  Land Use 8
  Non-Native Species 9
  Hydromodification 9
Key Findings and Identified Habitat-Limiting Factors 11
Data Gaps 12
Early Action Recommendations 12

3.8 NEWAUKUM CREEK SUBBASIN



PHYSICAL DESCRIPTION

SUBBASIN

The Newaukum Creek (09.0114) subbasin drains an area of approximately 27.8 square miles. It flows from the mountains east of Enumclaw, across the Enumclaw Plateau, and enters the Green River at River Mile 40.7. The creek and its tributaries lie totally within the boundaries of King County. Portions of the subbasin lie within the Urban Growth Boundary (UGB).

The subbasin land area can be broken into the three segments:

- The upper subbasin (25 percent of the land area);
- The Enumclaw Plateau (57 percent of the land area); and
- The ravine (18 percent of the land area).

Newaukum Creek is unique in this reach of the Green River due to the large size of its drainage basin, flow, biological utilization and geographic location. It is one two large tributaries that flow into the middle reaches of the Green River, and is the most significant post-dam source of spawning gravel in to the middle reach of the mainstem Green River.

STREAM COURSE AND MORPHOLOGY

Newaukum Creek is approximately 14.0 miles long, and has eight tributaries that provide an additional 13.5 miles of stream length.

Its headwaters are formed by diffuse springs, snowmelt, and groundwater runoff in the 2,500- to 3,900-foot elevation range of Boise Ridge (a feature of the Grass Mountains, which are a part of the foothills to the Cascade Mountains).

The mainstem Newaukum Creek (09.0114) and the North Fork Newaukum Creek (09.0122) drop down steep ravines and gullies to the Enumclaw Plateau, where they join and flow across a relatively low-gradient area. The Osceola Mudflow originated from historic eruptions of nearby Mt. Rainier approximately 4,800 years ago and is the dominant geologic feature forming the Enumclaw Plateau. This mudflow was responsible for the deposition of large areas of unsorted clay sediments, which in turn have created a flat riverine topography.

After flowing across the plateau, they again enter a steep-walled ravine for the last three river miles before entering the Green River.

Newaukum Creek (RM 0.0 – 14.0) is subdivided into three channel types (Figure HM-2):

- The upper subbasin (RM 14 to RM 9) is classified as a High Gradient Contained Channel.

- The Enumclaw Plateau (RM 9 to RM 3) is classified as a Floodplain Channel (the channel is unconfined and has a gradient of 0.5).

- The ravine (RM 3) is classified as a Moderate Gradient Mixed Control Channel (the gradient increases to 2.7 percent (Boehm 1999). The channel is moderately to tightly confined but an area near the mouth of the creek has been severely altered by local landowners. The ravine extends to the confluence with the Green River, with only a short segment of alluvial fan (about 1,500 feet) extending into the Green River valley.

SALMONID USE

The known freshwater distribution of anadromous salmonids is depicted in the report Appendix. The presumed upstream distribution by chinook, coho and steelhead has been estimated by identifying the location at which the channel gradient steepens to over 12 percent. For Newaukum Creek, this 12 percent gradient break occurs at approximately RM 13.5 (Cutler 2000), about a half a mile upstream of an impassable cascade near RM 13.0 identified by Williams et al. (1975). The WDFW Spawning Ground Survey database indicates chinook have been observed upstream as far as RM 11.3, and that sockeye, coho, sockeye and chum salmon (along with winter steelhead adults) have also been observed spawning in the Newaukum Creek subbasin. Resident and anadromous cutthroat have been observed throughout the streams and lakes.

No attempt is made in this report to include abundance estimates of salmon and steelhead in this subbasin. However, the subbasin is considered to be a major producer of winter steelhead, coho and chinook salmon (Washington Department of Fish and Wildlife and Western Washington Treaty Indian Tribes 1994). During typical years, hundreds of adult chinook and adult coho salmon enter this subbasin to spawn. Malcom (1999) calculated that between 1986 and 1997, a mean of 15.6 percent of the naturally spawning adult chinook salmon that entered the Green River Basin (excluding Soos Creek because of the large hatchery returns), spawned in the lower 4 miles of Newaukum Creek.

FACTORS OF DECLINE

FISH PASSAGE

Known barriers to anadromous salmonids are shown in the reportAppendix.

King County is conducting (completion date early 2001) a comprehensive Green River Basin investigation of culvert and bridge crossings of county roads. This investigation should produce a basin-wide database identifying anthropogenic barriers or constrictors of stream channels.

In 1998, a culvert and remnants of an old dam were removed from RM 2.0 of the North Fork Newaukum Creek in order to improve access for anadromous salmonids to 1,200 meters of habitat. Subsequent smolt trap monitoring at the project site documented coho and trout use upstream (Dimock 2000).

Deposition of gravel at the mouth of Newaukum Creek where it enters the Green River floodplain has created a small alluvial fan that has impeded fish migration in at least two years (see Sediment Condition, below). Passage impediments are further exacerbated by the lack of deep holding pools on the fan (see Hydromodification) and throughout the lower mile of channel in Newaukum Creek (Malcom 1999).

Shallow or subsurface flows (see Hydrology—Low Flows) have impeded the upstream migration of adult chinook salmon into Newaukum Creek, especially the early run component (Malcom 1999; Boehm 1999).

RIPARIAN CONDITION

Riparian habitat is severely degraded in this subbasin and is believed to be contributing to the decline of natural salmonid production within this subbasin. The headlands of both Newaukum Creek and the North Fork of Newaukum Creek are used for commercial timber production.

From RM 10.0 to RM 4.0, the riparian habitat consists of a narrow (typically less than five meters wide) strip of vegetation (pers. comm. R. Fritz as reported in Malcom 1999). The forest can best be described as in transition. With the cooperation of landowners and local enhancement groups, selected locations between RM 3.0 and RM 10.5 have undergone riparian vegetation enhancement to widen the habitat (Anderson, 2000).

Because of the importance Newaukum Creek has for anadromous salmonids (particularly chinook), there have been at least two recent comprehensive surveys of the lower reaches of the mainstem creek. Boehm (1999) and Malcom (1999) separately examined the lower river mile. The riparian habitat in the lower mile consists of second-growth deciduous hardwoods and shrubs with a few conifers.

At approximately RM 0.5 the riparian forest begins to mature as additional numbers of coniferous trees are present, consisting of western red cedar, Sitka spruce, Douglas fir (*Pseudotsuga menziesii*), and western hemlock (*Tsuga heterophylla*). The deciduous trees are also more mature, with older big leaf maples and red alders present. The shrub layer also includes snowberry (*Symphoricarpos alibis*), red elderberry (*Sambucus racemosa*), indian plum (*Oemleria cerasiformis*), sword fern, and devil's club (*Oplopanax horridus*) (Boehm 1999).

Young deciduous soft and hardwoods dominate the riparian zone of the lower 0.5 river miles of Newaukum Creek. Young red alders (*Alnus rubra*), scattered 20- to 30-year-old black cottonwoods (*Populus trichocarpa*), and big-leaf maples (*Acer macrophyllum*) dominate this reach. There are a few young western red cedars and Sitka spruce. The understory shrub layer consists of Himalayan blackberry (*Rubus discolor*), salmonberry (*R. spectabilis*), willows (*Salix spp.*), vine maples (*Acer circinatum*) and red-oiser dogwood (*Cornus stolonifera*).

Between 1996 and 1997, approximately 1,155 feet of the stream channel was realigned beginning at approximately RM 0.1 upstream to 0.25. During this time, the right bank was cleared, riprapped within the floodplain, and sprayed with a herbicide (pers. comm. Doug Hennick (WDFW) reported in Boehm 1999).

LARGE WOODY DEBRIS

There is no quantitative information on the historic abundance of LWD in Newaukum Creek. In the 1950s, LWD was reportedly systematically removed from lower Newaukum Creek to protect a bridge located approximately 1,000 feet upstream of the confluence with the Green River (Boehm 1999).

Separate investigations by both Malcom (1999) and Boehm (1999) indicate that the quantity and quality of pools, riffles and LWD in the lower Newaukum Creek are insufficient. When NMFS habitat rating parameters (NMFS 1995) are applied Malcom' data, this reach of Newaukum Creek is rated as "Not Properly Functioning" for LWD. Malcom concluded that the habitat quality in this reach would continue to decline due to the age and condition of the riparian corridor and passive restoration would not be successful in the near term.

Data concerning current LWD amounts elsewhere in the Newaukum Creek subbasin is lacking. However, observations (Malcom pers. comm.; Nelson pers. comm., Boehm 1999) indicate that amounts of LWD are low and possibly average five pieces per 100 meters of stream. When NMFS criteria (NMFS 1995) is applied to LWD amounts in this range, the entire subbasin would be rated as "Not Properly Functioning."

Severe scouring and a lowering of the stream channel of the Newaukum Creek bed (see Hydrology, and Sediment Condition—Scouring, below) has thwarted attempts to place wood in the streambed (Malcom 1999).

HYDROLOGY

LOW FLOWS

Because alluvial fans are formed of deep, porous deposits of generally coarse sediment that readily transmits water, streams flowing across such sites are naturally highly vulnerable to low or subsurface flows (Levin 1981).

The Muckleshoot Indian Tribe conducted a low flow trend analysis for Newaukum Creek to determine if surface and ground water withdrawals were reducing stream low flows (Malcom pers. comm.). The analysis of 7-day low flows from 1967 to 1992 did not indicate a declining trend.

However, data from two other studies (Carlson 1994; Culhane 1995) indicate evidence to the contrary.

Carlson's study examined three streams similar in drainage basin size to Newaukum Creek. He concluded that declining flows were not caused primarily by declines in precipitation, but by water withdrawals.

Culhane's analysis of data from 1953 to 1992 showed a significant decline in 7-day low flows. The analysis in this investigation found an estimated 20 percent decline in mean annual flows and a 24 percent decline in low flows from 1953 to 1992When the decline in annual precipitation is compared to the measured declines in Newaukum Creek subbasin's mean annual flows and low flows, it suggests that precipitation alone is not responsible for the declining stream flows. It is reasonable to conclude that a combination of water withdrawal (surface and ground water), the conversion of historic forest lands to agricultural lands, and the elimination of the historic wetland complex of the Enumclaw Plateau have contributed to a reduction in the low flows of Newaukum Creek in the reaches of the Enumclaw Plateau and further downstream. The reaches of Newaukum Creek and the North Fork Newaukum Creek upstream of the Enumclaw Plateau are predominantly in private commercial timberland. The impacts of this land use management on flows within this reach and downstream are not known. The average 7-day low flow generally occurs during the period when chinook salmon are migrating upstream, suggesting that additional areas of low flow concerns may be present in Newaukum Creek.

WATER RIGHTS AND CLAIMS

Culhane (1995) indicated that there are 41 ground water rights in the Newaukum Creek subbasin. Three of these are for municipal use and represent 56 percent of the allocated instantaneous water quantity and 75 percent of the annual water quantity. While the majority of the number of water rights and claims in the subbasin are for irrigation and small domestic systems, the majority of the water used is for domestic purposes. Table Newaukum-1 shows water rights and claims.

NEW-1: Newaukum Creek Subbasin Water Rights

Source	Total Number of Water Rights	Qi (cfs)	Total Number of Water Claims	Qi (cfs)
Ground	41	14.2	163	6.3*
Surface	36	8.4	32	1.2

Source: Culhane 1995.
* = Estimated quantities

The tributaries to the Green River have been closed to additional surface water withdrawals since 1980 (Chapter 173-509 WAC). Potable water wells that produce less than 5,000 gallons per day are exempt to a water right requirement. It is not known how many of these wells are present in the subbasin and what their cumulative impact might be.

SEDIMENT CONDITION

SCOUR

From RM 0.0 to RM 3.0, Newaukum Creek traverses a steep ravine. Soils in this ravine have been classified as a mixture of Alderwood and Kitsap soils (SCS 1985). These soil types exhibit a natural tendency to erode and become unstable, and this is exacerbated by historic land use practices within the ravine (e.g., timber removal and clearing for upland development). Scour has removed much of the suitable substrate in this reach and deposited gravels at the mouth of Newaukum Creek. In some years, this gravel fan can create a barrier to the upstream migration of adult chinook. In 1996 and 1998, a channel had to be hand excavated through this gravel bar to allow for upstream chinook migration. No adult chinook had been observed in Newaukum Creek prior to this excavation . Adult chinook were observed spawning immediately after the channel was excavated (pers. comm. R. Fritz as reported in Malcom 1999).

Scour surveys conducted by MIT indicate that Newaukum Creek has sufficient flows to scour salmon redds during periods when eggs would be incubating (MIT 1996). During 1997, in the lower mile of Newaukum Creek scour was so extreme that the scour survey chains could not be recovered because over 14 inches of scour occurred.

Gravels are transported rapidly through the reach and deposited in lower-gradient stream reaches. Boehm (1999) found the lower river mile of Newaukum Creek to be a mixture of large gravel (35%), cobble (30%), small gravel (20%) and sand (15%). The stream reach that had the poorest spawning gravels was the lower 1,500 feet that had been channelized by a private landowner (see Hydromodification).

A desired pool-to-riffle ratio is 1:1. Typically, as structure (LWD) is eliminated, the ratio shifts towards a riffle-dominated reach. Newaukum Creek is deficient in LWD (see Large Woody Debris, above). In many places in lower Newaukum Creek, the streambed is eroded down to a stable channel bottom with long riffle sections (Williams 1975). These long riffle sections limit holding areas (pools) for adult and juvenile salmonids and rearing areas for some species of salmonids. When NMFS habitat rating parameters (NMFS 1995) are applied Malcom's 1999data, this reach of Newaukum Creek is rated as "Not Properly Functioning" for pool frequency and quality, and for off-channel habitat.

The lower 500 feet of Newaukum Creek flow across the floodplain of the lower Green River, forming an alluvial fan composed of cobble and smaller sized sediments. No data on the historic extent or distribution of gravel bars was located. A gravel bar that has built up at the confluence with the Green River currently impairs upstream migration of adult chinook at some flows (Malcom 1999). The gravel bar may be an intermittent migration impediment as during a October 2000 field review it was observed that the channel had regraded to a consistent 2 percent grade through the bar (Tom Nelson, pers. com.). No additional information on the existing or historic extent of gravel bars in the remainder of Newaukum Creek was located during the course of this investigation.

The Moderate Gradient Mixed Control segment of Newaukum Creek (RM 0.3 to RM 4) is essentially unconfined by levees, revetments or riprap (Malcom 1999). No information was located describing current artificial channel constraints upstream of RM 4.0 in Newaukum Creek.

WATER QUALITY

Newaukum Creek is not listed on the Washington State Department of Ecology (WDOE) 1998 303(d) list for water quality problems associated with high temperatures or low dissolved oxygen. However, temperatures greater than the NMFS criteria for properly functioning habitat (57^{o}F) have been recorded at the USGS gage near RM 1.0 (Malcom 1998).

While not directly an adverse impact to salmonids, there are numerous reaches of Newaukum Creek listed on the WDOE 303(d) list for exceeding allowable fecal coliform limits. Samples taken at 11 stations (RM 0.9 to RM 10.8) all met the criteria to be listed on the 303(d) list. This is more of an indicator of current land use practices that may be adversely impacting the natural reproduction of salmonids.

High turbidity discharges typically occur each year during high flows in Newaukum Creek, resulting in downstream turbidity plumes in the mainstem Green River. Malcom (pers comm.) noted that on October 29, 1997, the water discharge from Newaukum Creek created such high turbidity in the Green River that chinook redds could not be identified and enumerated for as far as 4 miles downstream of the mouth of Newaukum Creek. The specific source of these high-flow discharges is currently unknown, but it appears that contributions from the commercial forest production lands, runoff from agricultural lands, and direct incision of tributary stream channels near agricultural lands may all be sources. This increased turbidity and its impacts should be further investigated, since water quality problems associated with increases in turbidity may be a limiting factor to natural salmonid production in this subbasin and immediately downstream in the mainstem Green River.

LAND USE

The Newaukum Creek subbasin is one in transition from historic forested lands to agriculture and now to rural residential.

Land use in the headwater reaches zone consists primarily of commercial forest production with minor impacts by development to date. This area is located outside the Urban Growth Boundary (UGB) and most probably will remain in commercial forest production in the future. The upland part of the basin accounts for approximately 25 percent of the land area.

Agriculture (predominantly in the form of pasture) is the major land use on the Enumclaw Plateau. The subbasin currently has a diverse development pattern, ranging from low-density residential and pasture uses to high-density residential and commercial land uses. Presently, most commercial and low-to-high-density residential land uses are situated within the UGB. The UGB encloses an area beyond the incorporated city limits of Enumclaw and faces likely future annexations and zoning changes. These future land use changes within the UGB will lead to increases in impervious-area percentages in the subbasin. The Enumclaw Plateau area occupies approximately 57 percent of the subbasin.

Forestry has been the historical land use within the ravine area. However, an increasing number of single-family residences are appearing in the ravine area. The ravine reach accounts for about 18 percent of the basin area.

NON-NATIVE SPECIES

ANIMALS

No known exotic fish species are believed to occur in the waters accessible to anadromous salmonids of this subbasin. It is likely that warmwater fish occur in some of the farm ponds and lakes of the Enumclaw Plateau.

PLANTS

Reed canarygrass (*Phalaris arundinacea*) is abundant throughout this subbasin.

Neither non-native plant or animal species are believed to be a limiting factor to natural salmonid production in this subwatershed.

HYDROMODIFICATION

Channelization and bank modifications have altered channel morphology in the short alluvial fan of Newaukum Creek. Between 1984 and 1990, a landowner periodically bulldozed and re-aligned Newaukum Creek between RM 0.1 and RM 0.3, straightening meanders and piling LWD in the old channel to force flows into the newly excavated channel (Boehm 1999). In addition, the riparian zone was cleared and recently riprapped just downstream of RM .01 to protect a septic and well system (Boehm 1999).

OFF CHANNEL HABITAT

This riverine topography, when combined with numerous depressions has formed a complex of wetlands across the landscape of the Enumclaw Plateau. The historic wetlands of this subbasin were large enough that many have been named (King County 1990a). They include:

- Newaukum Creek No. 21 (158 acres);
- Newaukum Creek No. 51 (144 acres);
- Newaukum Creek No. 22 (63 acres);
- Newaukum Creek No. 14 (45 acres); and Newaukum Creek No. 31 (29 acres).

Most of these wetlands have been converted into agricultural lands (primarily pastures) through ditching, draining and filling activities over the past 100 years.

FLOODPLAIN CONNECTIVITY

Floodplain development is naturally limited in the High and Moderate Gradient Contained Channel segment, thus human activities have not substantially altered floodplain connectivity in upper (RM 9 to RM 14) or lower (RM 0 to RM 5) reaches of Newaukum Creek.

No quantitative data on historic or current floodplain connectivity was locate. However, the floodplain segment of Newaukum Creek (RM 5 to RM 9) is associated with a floodplain that typically would be able to support inundation-tolerant vegetation, contain side- and off-channel habitats, and serve as a groundwater re-charge zone. The palustrine channel segment is described as “cutting through pasture and flat farmlands with very little natural growth available to provide shade and protection to the creek” (Williams et al. 1975). Agricultural and rural residential development have continued to influence habitat in the palustrine segment of Newaukum Creek, and have resulted in altered floodplain function. In many places, the mainstem Newaukum Creek streambed is eroded down to a stable channel bottom with long riffle sections (Williams 1975).

Many of the tributaries to Newaukum Creek have been channelized into roadside and drainage ditches. The lower three miles of Newaukum Creek flow through a deep, confined ravine. The lower 500 feet of Newaukum Creek currently has a moderate gradient (about 2%) and during seasonal low flows a blockage to adult chinook may exist at the mouth (See Sediment Condition, above). The mainstem Newaukum Creek does flood in some localized areas, particularly in areas upstream of constriction points such as undersized culverts and riprap (Kerwin, pers. obs.).

There was no available data located on the historic frequency of off-channel habitats in Newaukum Creek. Based on channel type, it is expected that off-channel habitats are likely to be present only in the 1,500 foot long reach where the alluvial fan crosses the Green River floodplain or in the Palustrine segment (RM 5 to RM 10) under undisturbed conditions. There are considerable numbers of off-channel habitats between RM 2 and 3. These off-channel habitats consists of numerous side channels, many of them 100 meters or greater in length that have associated extensive wetland complexes. Numerous braided stream channels are visible from aerial photographs. Off-channel habitats are expected to be rare in the High Gradient Contained segment (RM 10 to RM 14) because the confining valley walls effectively limit lateral migration.

Surveys of lower Newaukum Creek conducted in 1998 categorized the area between RM 0 and RM 0.6 as having “few or no backwaters and no off channel ponds” (Malcom 1999) and are assumed to be representative of the entire Moderate Gradient Mixed Control segment. There is no information on the current extent of off-channel habitat available in the Palustrine segment between RM 5 and RM 10.

FLOODPLAIN CONNECTIVITY

Approximately 1,155 feet of the stream channel were realigned between 1996 and 1997 beginning at approximately RM 0.1 upstream to 0.25. This activity has reduced stream channel complexity (pers. comm. Doug Hennick (WDFW) as reported in Boehm 1999). In response to the channelization, an adjacent landowner attempted to protect his property by clearing and riprapping the right bank (as well as removing LWD and applying herbicide to vegetation within the riparian zone).

KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- The virtual absence of LWD is believed to be a limiting factor to natural salmonid production in this subbasin.

- Stream scour is exacerbated by uncontrolled stormwater runoff from upstream roads that have no stormwater controls, farms, and urban areas in Enumclaw. Scour and bedload movement are believed to be a limiting factor to natural salmonid production throughout Newaukum Creek subbasin.

- Channel conditions are believed to be a limiting factor to natural salmonid production in this subbasin.
- There is a general lack of riparian habitat information for this subbasin.

- Newaukum Creek is the first significant source of stream transported spawning gravels for the mainstem Green River downstream of HHD.

- The Newaukum Creek subbasin supports significant numbers of spawning chinook along with coho, winter steelhead, chum, sockeye and coastal cutthroat.

- The lower 0.3 miles of Newaukum Creek have been dredged and straightened by private landowners.

- Stream cleaning and riparian harvest have reduced the frequency of LWD in the lower 1.4 miles of Newaukum Creek to 0.3 pieces per channel width, a level considered "poor" or "not properly functioning". Pools are also scarce.

- Although the subbasin is undergoing a transition from forest to rural and urbanization land use there is still significant portions of the subbasin that could be effectively restored.

- Summer low flows are decreasing.

- Although no quantifiable information was available, it was the professional judgement of Technical Advisory Group members that the riparian buffer in this subbasin was insufficient. This is in at least partly due to current and historic land use practices.

- There is a lack of LWD throughout the streams in this subbasin.

- Summer low flows have decreased in the Newaukum Creek subbasin. These low flows effectively limit available rearing production for species of salmonids that require over-summer residency.

- Water quantity (both seasonal low flows and winter storm flows) due to changes from historic land use patterns and withdrawal, are limiting the natural production of salmonids in this subbasin.

DATA GAPS

- Little data available on hydromodifications channel condition, LWD and other critical habitat conditions or habitat in the Newaukum Creek Subwatershed.

- The impacts of seasonal high flow peaks and durations on salmonid production should be determined.

- Water quality, particularly during stormwater events and potential adverse impacts to salmonids are unknown.

- Actual, instantaneous water use within the basin is not known.

- There was no data available that provided the location and magnitude of mass wasting sites.

EARLY ACTION RECOMMENDATIONS

- Conduct a comprehensive inventory of current salmonid habitats.

- Conduct a comprehensive barrier assessment and habitats upstream of identified anthropogenic.

- Because of this lack of site specific habitat data, comprehensive base line habitat surveys should be initiated. These surveys should at a minimum include an inventory of LWD, riparian habitats present, quality and quantity of spawning gravels, quality and quantity of pool, an evaluation of streambank stability and associated mass wasting and erosion/sedimentation problems. We need to more adequately understand the spatial dynamics and distribution of LWD and associated habitats and identify opportunities for accelerated riparian forest recovery. To accomplish this, counts of wood loading, distribution and characteristics over time at key locations stratified by stream order, elevation and channel reach type, gradient, riparian zone features (width, species composition and age composition) should be made.

- A water use and water level monitoring program should be established.

- Additional water flow data should be gathered to provide more certainty about long-term flow trends in this subbasin.

LIST OF TABLES

NEW-1: Newaukum Creek Subbasin Water Rights

3.9 COAL AND DEEP CREEKS SUBBASINS

Physical Description 2
  Subbasin 2
  Stream Course and Morphology 2
  Salmonid Use 3
Factors of Decline 3
  Fish Passage 3
  Riparian Condition 3
  Hydrology 3
  Sediment Condition 5
  Water Quality 5
  Land Use 5
  Non-Native Species 5
Key Findings and Identified Habitat-Limiting Factors 5
Data Gaps 6

3.9 COAL AND DEEP CREEKS SUBBASINS

PHYSICAL DESCRIPTION

SUBBASIN

Coal (09.0126) and Deep creeks (09.0142) are grouped together in this report because of their close geographical location and their influence on groundwater. Neither of the creek systems are directly linked by surface connection to the mainstem Green River, and both drain into small lakes that do not have surface water outlets.

However, their importance to anadromous salmonids lies in the theory that water from these lakes seeps underground and surfaces as perched springs and/or riverbed springs in the Green River streambed in the vicinity of RM 48 – 50. Other lakes in the vicinity (i.e., Muskrat Lake) may also contribute to these springs.

STREAM COURSE AND MORPHOLOGY

COAL CREEK

Coal Creek is approximately 9.2 miles long. Its 15 tributaries have approximately 8.0 miles of combined additional stream length. The mainstem of Coal Creek empties into Fish Lake (which is only 3,500 feet west of Deep Lake). Fish Lake is located 729 feet above sea level, encompasses 16.5 surface acres, and has a maximum depth of 22 feet (Wolcott 1973). The basin lies largely below 2,500 feet in elevation and is subject to rain or snow events.

DEEP CREEK

Deep Creek is approximately 4.8 miles long. Its three small tributaries add approximately 1.5 additional stream miles. This creek drains into both Hyde and Deep Lakes. It is believed that both lakes are important groundwater source to the mainstem Green River (Wolcott 1973; Williams 1975).

Hyde Lake (sometimes referred to as Elizabeth Lake) is located approximately 2,300 feet north from Deep Lake at approximately 800 feet in elevation with a surface area of 5.4 acres (Wolcott 1973). The only water supply is from Deep Creek is via a small stream channel. Wolcott (1973) theorized the lake’s outlet is subsurface to springs along the Green River.

Deep Lake is fed by Deep Creek and is located at approximately 770 feet in elevation with a surface area of 39.0 acres, a maximum measured depth of 76 feet. It is approximately 3,500 feet east of Fish Lake (Wolcott 1973). Wolcott (1973) and Williams (1975) theorized the lake’s outlet is subsurface to the springs along the Green River between RM 48-50.

SALMONID USE

COAL CREEK

Cutthroat trout have been observed (Phil Schneider, WRIA 9 map info) and reported to use Coal Creek (Don Finney pers. comm.). Locations of the observations are noted in the report Appendix.

DEEP CREEK

No observations were recorded for Deep Creek as part of the WRIA 9 mapping effort.

FACTORS OF DECLINE

FISH PASSAGE

Fish Passage information on these systems is limited at this time.

RIPARIAN CONDITION

The commercial timber in the middle reaches of both the Coal and Deep creek subbasins have largely been logged and replanted at various times in the last 25 years (Kerwin 2000). Fire scars are also present along some hillsides. Deep Lake State Park affords some protection for the riparian zone around the lake.

LARGE WOODY DEBRIS

LWD information on these systems is limited at this time.

HYDROLOGY

COAL CREEK

Coal Creek serves as the water source for Fish Lake and the lake does not have a surface water outlet. During seasonal low flows, water flows in Coal Creek are subsurface in some locations. No surface flows were observed in Coal Creek at the culvert immediately upstream of Fish Lake on October 30, 2000 (Kerwin, 2000). As the flows in Coal Creek diminish, the water surface elevation of Fish Lake begins to drop. These water surface elevations in fluctuate substantially from full pool at 729 mean sea level (m.s.l.) during the springtime to nearly empty at 694 m.s.l (Higgins 2000) during late summer and early fall. Water flows from Icy Creek Springs also begin to decrease throughout summer months and reach their lowest levels when the water surface elevation in Fish Lake is lowest (Mercer 2000).

Observations of the stream channel in the vicinity of Fish Lake and at the Cumberland-Kanaskat Road on October 30, 2000 indicate that the stream was deeply incised and was capable of carrying sizeable high flows.

It has been theorized that the glacial drift that underlies Fish Lake is sufficiently permeable to allow for the total infiltration of lake water rather than the lake having a surface water outlet. Previous studies (CH2M, Hill/Long and Associates, 1991; Brown and Caldwell, 1989; TCW Associates, 1989) concluded that this infiltrated water reemerges as the large-volume springs along the eastern banks of the Green River between RM 48 and RM 50. These springs include the Fish Hatchery Springs at Icy Creek, Black Diamond Springs, Palmer Spring, and Resort Spring. The exact path that this infiltrated water takes is not known but is thought to be controlled by the glacial drift and the buried topography of the bedrock contact with the glacial drift.

Water from the Icy Creek Springs is utilized for fish propagation purposes by the Washington Department of Fish and Wildlife. During low flow periods the rearing ponds are able to capture all the water flowing from these springs and flow measurements are taken monthly as they exit the rearing ponds. During seasonal high flows, the piping system into the ponds is not capable of handling the entire spring flows and flows are estimated. The range of these flows are shown in the table ICY-1. Springflows typically peak during the winter months when precipitation and lake levels are the highest and are they are at their lowest in October and November when lake water levels are low and groundwater is being recharged. Water temperatures as measured at the hatchery rearing pond typically range from 42 F (February) to 50 F (August) (Mercer 2000).

Table Coal-1: Icy Creek Rearing Ponds and Springs (Mercer 2000).

Month	Water Flows (gpm)
January	3700 - 5300
February	3700 - 5300
March	4000 - 5450
April	5300 - 5800
May	2800 – 5100
June	2800 - 3100
July	2500 - 3100
August	2600 -3300
September	1100 – 1580
October	700 - 915
November	1300 – 4500
December	3400 - 3900

The impacts on ground water hydrology at a proposed gravel surface mining operation in the vicinity of Fish Lake has caused some concerns about spring flow at the Icy Creek Spring.

No information on stream flows was located during the course of this investigation.

DEEP CREEK

The surface water elevation of Deep Lake is reported to fluctuate 12-15 feet with lower lake surface elevations reported during late summer and early fall during seasonal low flow conditions (Johnson 2000).

No information on stream flows was located during the course of this investigation.

SEDIMENT CONDITION

Sediment conditions are not applicable given the unique situation of these two stream systems.

WATER QUALITY

Water quality as monitored at the Icy Creek Springs and Black Diamond Springs indicates that both creeks meet or exceed all state water quality criteria for Class AA state waters.

LAND USE

Land use within the upper and middle reaches of both creeks is primarily commercial timber production. In the downstream reach land use is rural residential with a mixture of single family homes and hobby farms. Deep Lake is surrounded by Deep Lake State Park.

NON-NATIVE SPECIES

ANIMALS

Fish Lake and the headwater lakes have been planted with non-native rainbow trout but as previously stated the lake does not have direct surface water contact with the Green River. With the unique situation of these stream systems, the presence of non-native animal species in upstream reaches does not appear to have any adverse impacts to anadromous stocks.

PLANTS

The only non-native plant species observed in the vicinity of the Icy Creek and Black Diamond Springs was Himalayan blackberries.

Hydromodification

The surface elevations of Fish, Deep, and Hyde lakes are naturally controlled. There are several road crossings where culverts are utilized, but these do not appear to be fundamental habitat-limiting factors.

Hydromodification is present at the spring intake systems at Icy Creek (for non-consumptive use) and Black Diamond Springs (for consumptive use). Both facilities use low-head dams to divert water.

KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- The lakes provide an important function in maintaining springflows in the Green River between RM 48 – 50.

- No habitat-limiting factors were identified at this time.

DATA GAPS

- Stream flows, lake elevations and their relationship with spring flows should be established.

- The proposed gravel surface mining operation in the vicinity of Icy Creek and its potential impact to spring water should be verified.

LIST OF TABLES

Table Coal-1: Icy Creek Rearing Ponds and Springs (Mercer 2000).

3.10. UPPER GREEN RIVER AND SUNDAY CREEK WATERSHED ADMINISTRATIVE UNIT

Executive Summary....2
Upper Green River and Sunday Creek WAUs....14
SUMMARY....28
Data Gaps....30
Key Findings and Identified Habitat-Limiting Factors....30

3.10. UPPER GREEN RIVER AND SUNDAY CREEK WATERSHED ADMINISTRATIVE UNIT

EXECUTIVE SUMMARY

SUBBASIN

The Green River, upstream of River Mile 64.5 has been divided in to five Watershed Administrative Units (WAUs). WAUs are drainage basins delineated by the Washington Department of Natural Resources (WDNR) for the purpose of conducting Watershed Analysis. The purpose of a Watershed Analysis is two fold and dependent on land ownership. For State and private lands the purpose is to address the cumulative effects of commercial timber harvest upon public resources such as the Northern Spotted Owl or salmonids. This is for the purpose of maintaining a manageable land unit size in order to meet the intended timelines as established by the Washington Forest Practices Board.

For federal lands which are managed under the provisions of the Northwest Forest Plan, the purpose is to meet the watershed analysis requirements established in the Record of Decision for Amendments to U.S. Forest Service and Bureau of Land Management Planning Documents within the range of the Northern Spotted Owl, April 13, 1994.

Both of these processes are not decision making processes, but are intended to be used in a manner to set the stage for subsequent decision making processes. Both characterize ecosystems, or portions of ecosystems, by highlighting problem areas and suggesting solutions on a watershed scale.

Within the State and Private lands, a Watershed Analysis in four of the five WAUs in the upper Green River Subbasin have been completed and three of these have been released. Forest management recommendations have been approved for the Lester WAU and drafts are currently being reviewed for the Howard Hanson, Smay Creek, Upper Green River and Sunday Creek WAUs. The North Fork Green River WAU report has not been started.

Under the federal process, the Green River Watershed Analysis (U.S. Forest Service 1996) has been completed and released.

For the purposes of this report we will attempt to summarize, by WAU, the current habitat conditions and document the potential for recovery of the impaired habitats.

WATERSHED ANALYSIS METHODS

Because the methodology used in watershed analysis is somewhat unique, it is useful to outline that methodology. Stream segments are selected to represent an array of geomorphic channel types of salmonid bearing streams. Gradient, confinement, and bankfull width, are the parameters in which to base the selection. Other features such as land-use, riparian conditions, aspect, and channel disturbance history provide additional considerations for representation. Because the objective of this analysis is to determine habitat features and factors that limit natural salmon production in the respective WAUs, segment selection is targeted on known salmonid-bearing streams and those that met the physical criteria to qualify as fish-bearing as defined by the draft stream typing emergency rule (later adopted on November 14, 1996). Delineation of the segments is initially done using topographic maps and aerial photos, then field verified during the surveys. Also, old aerial photographs helped to visually assess channel character in an undisturbed state (prior to forest management) and hypothesize habitat potential [1942 (partial coverage) and 1958 (first complete stereo coverage)].

Surveyed stream segments are grouped into geomorphic channel classifications for sub-basins within the two WAUs. Based on the work of Montgomery and Buffington (1993), Pleus and Schuett-Hames (1998), O'Connor (1997), as well as considering the actual distribution of segments surveyed, groupings in the Green River and Sunday Creek WAUs were sorted into 3 classes of channel gradient, 3 classes of confinement, and 5 classes of bankfull width for a total of 45 possible combinations. These classes and their criteria for inclusion are provided in table Upper Green-1.

<table>
<tr><th colspan="8">Table Upper Green-1. Matrix of Possible Channel Classifications Used to Group Segments for the Purpose of Establishing Geomorphic Units.</th></tr>
<tr><th>Geomorphic Feature</th><th colspan="7">Criteria</th></tr>
<tr><td>Gradient (%)</td><td colspan="2">0-2</td><td colspan="3">>2-8</td><td colspan="2">>8-20*</td></tr>
<tr><td>Confinement</td><td colspan="2">Unconfined (valley width > 4 channel widths)</td><td colspan="3">Moderately confined (valley width 2-4 channel widths)</td><td colspan="2">Confined (valley width < 2 channel widths)</td></tr>
<tr><td>Bankfull width (m)</td><td>0-5</td><td colspan="2">>5-10</td><td>>10-15</td><td colspan="2">>15-20</td><td>>20</td></tr>
<tr><td colspan="8">*No streams were surveyed with gradients exceeding 20%.</td></tr>
</table>

FIELD MEASUREMENTS AND OBSERVATIONS

Information sources to determine sampling sites include topographic maps (USGS), aerial photographs (1989), and fisheries distribution information (WARIS). Sampling sites are prioritized based on (in descending order of importance): a) the location of fish producing (or potentially producing) stream reaches; b) the need for verification of geomorphic character; and c) riparian diversity. Typically physical habitat sample reaches are 100 meters in length. The analyst surveyed one to three evenly distributed reaches within a segment.

In the Green River and Sunday Creek WAUs, stream surveys are conducted and completed during moderate to low flow conditions from July through September 1995. The sampled parameters were quantitatively assessed using methodologies for field habitat collection outlined in the State's Ambient Monitoring Manual (Schuett-Hames et al., 1994), the U.S. Forest Service Stream Handbook, and the Watershed Analysis Manual Version 3.0. Sediment samples were collected in riffle crests in accordance to the method of Schuett-Hames et al. (1994) using a McNeil core sampler, and analyzed by the gravimetric method. Temperature recordings were obtained by maximum thermometers, and thermographs recording at 1 hour intervals from July through September, also in accordance to the temperature monitoring methods of Schuett-Hames et al. (1994). Scour information was obtained using scour chains placed in suitable spawning area. Substrate data were categorized into six size classifications (based on the U.S. Forest Service Stream Handbook, 1991), and frequency of occurrence calculated. All visual observations of juvenile and adult fish were also recorded during the surveys to verify DNR Water Type maps.

A synopsis of the definitions used in this methodology as described in Schuett-Hames (1994) is included in table Upper Green-2. Minimum area and depths for a unit to be considered a pool are shown below in table Upper Green-3.

Table Upper Green-2. Definitions of Units and Terms Used in this Report.	
Term	**Unit Description**
Log or large woody debris (LWD)	For Washington State Watershed Analysis, a log, not part of a live tree greater, than 0.10 m (0.33 ft) diameter and greater 2 m (6.5 ft) in length. To qualify, the piece of wood must lie within the vertical axes of the bankfull width, or at least protrude into these vertical axes. If ten or more pieces are touching, it is considered a jam (jams are explained below). The NMFS defines LWD as a minimum of 0.6 m diameter and 15 m length
Key Piece	A log or rootwad independently stable in the stream bankfull width (not functionally held by another factor – see stability factors) and retaining or having the potential to retain other pieces of wood. The NMFS has no comparable parameter.
Rootwad	A rootball greater than 51 cm (20 in) in diameter and with a stem less than 2 m (6.5 ft) length. A stem longer than 2 m in length is considered LWD. To qualify, the piece of wood must lie within the vertical axes of the bankfull width, or at least protrude into these vertical axes. If ten or more pieces are touching, the piece is considered part of a jam (jams are explained below).
Wood Zone	Zone 1- Protruding into the low flow wetted channel surface. Zone 2- Not protruding into the wetted channel surface, but protruding below the horizontal axis of the ordinary high water mark (OHWM). Zone 3- Not protruding into zone 1 or 2, but protruding to within the vertical boundaries of the bankfull width (i.e. bridged or suspended over the channel).
Bankfull Width (BFW)	Bankfull width is the width of the channel at bankfull flow. It includes the BFW of all side channels and braids along the measured cross-section.
Log or Debris Jam	A cluster of ten or more touching pieces of wood with at least part of the jam located within zones one or two. To qualify as piece to be counted, the wood must meet the size requirements of LWD or a rootwad.
Category 1	The dominant unit within the cross section of the main channel, occupying at least 50% of the wetted channel width. There is only one category 1 habitat unit per linear length of the main channel.
Category 2	Units within, or adjacent to category 1 units, occupying less than 50% of the wetted channel width. Category 2 units are included in the total sum of the length of habitat units surveyed. Therefore, the total length of habitat units can exceed the total stream distance surveyed.
Category 3	Isolated channels, smaller than the main channel, connected to the main channel both at the upstream and downstream ends. Category 3 units are included in the total sum of the length of habitat units surveyed. Therefore, the total length of habitat units can exceed the total stream distance surveyed.
Category 4	Off-channel areas. These units are not defined in the Ambient Monitoring Manual, but are assigned to habitat units that provide off-channel rearing in summer or winter, but do not fall into any of the above categories. These units are typically wetlands that are not defined as the main channel, but are connected to it, and channels that are connected to the stream at only one point (i.e. not a side channel). Category 4 units are not included in the sum of the length of habitat units surveyed.
Residual Depth	The maximum depth minus the tail crest depth. This depth does not change with flow and can be measured even if the stream channel is dry.
Maximum Depth	The maximum depth of the sampled habitat unit. Unlike, residual depth, this measurement is influenced by flow.
LWD Total length	Measured distance from one end to the other end of the wood piece, including attached rootball. Logs are measured to the point where it no longer meets the minimum required diameter.
LWD Diameter	Measured at the mid-point of the log.
LWD Stability Factor	Factor responsible for the stability of the wood in the channel. A piece is either is stabilized by (1) a root system; (2) burial exceeding 50% of the length of the wood; (3) pinned by other pieces of wood, trees or rocks, or (4) is unstable.
LWD Sediment Storage	Wood that retains significant quantities of fine or coarse sediment of any size by influencing bed form. Wood does not need to be directly touching the stored sediment. Generally, fine sediments are those less than 0.85 mm in size
Sources: Schuett-Hames *et al.* (1994), WPFB (1997), and NMFS (1995, 1998). Important differences between State and Federal definitions are noted.	

Table Upper Green-3. Habitat Units.								
Minimum Area Criteria for Pools by Channel BFW					Minimum Residual Depth Criteria for Pools by Channel BFW			
BFW	Min. Unit Size				BFW	Min. Residual Pool Depth		
Metric	Imperial	Metric	Imperial		Metric	Imperial	Metric	Imperial
0-2.5 m	0-8 ft	0.5 m^2	2 ft^2		0-2.5 m	0-8 ft	0.10 m	0.3 ft
2.51-5 m	8.1-16 ft	1.0 m^2	10 ft^2		2.51-5 m	8.1-16 ft	0.20 m	0.7 ft
5.01-10 m	16.1-32 ft	2.0 m^2	20 ft^2		5.01-10 m	16.1-32 ft	0.25 m	0.8 ft
10.01-15 m	32.1-49 ft	3.0 m^2	32 ft^2		10.01-1 5 m	32.1-49 ft	0.30 m	1.0 ft
15.01-20 m	49.1-65 ft	4.0 m^2	43 ft^2		15.01-20 m	49.1-60 ft	0.35 m	1.1 ft
>20 m	>65	5.0 m^2	54 ft^2		>20 m	>65 ft	0.40 m	1.3 ft
Note: Minimum area required to form pool, riffle, tailout, cascade, or wetland habitat units. A habitat feature must meet the minimum size to be split from another unit. Pools must meet a minimum residual depth to qualify as a pool. Wetland units also include off-channel areas associated with the main channel, but not part of the main channel.								

Any presence of salmonids was determined by surveys that were conducted utilizing methods outlined in the Washington DNR Forest Practices Handbook, (DNR 1994), the Timber/Fish/Wildlife Ambient Monitoring Program Manual (Schuett-Hames 1994), and the Water Type Emergency Rule (Forest Practices Board, 1996). Other physical information collected in the surveys included habitat data, potential salmonid passage barriers, and evidence of recent disturbance (<20 years). Streams classified as Type 4 and 5 by the DNR water type maps were selected with priority given to streams on the basis of physical features that indicated a strong likelihood of salmonid presence (e.g. drainage area >50 acres, gradients <20 percent , low basin elevation, or any combination of these), although several streams beyond these parameters may also be surveyed at the discretion of the survey team. The basin areas selected were prompted by Watershed Analysis in other similar stream basins. Surveys are concentrated on visiting as many streams as possible over the three month survey period of each year.

SURVEYS

Surveys are conducted during sampling seasons that are typically during July to October. Survey seasons were limited to this particular window of opportunity to allow for a better chance to observe salmonids due to local salmonid life history cycles. The elevation of stream reaches has a bearing on the ability to observe salmonids. In the Green River Sunday Creek WAUs, the elevation is relatively high (1500-4000 feet) and resident salmonids or juvenile anadromous salmonids can be lodged deeply within gravels and organic debris. Typically, during colder air and water temperatures food sources are not present for feeding, thus making any salmonid detection more difficult. Also, high flows often occurring outside the survey window likely contribute to difficult detection of salmonids because they are either displaced downstream, under cover in inaccessible interstitial space, or are difficult to see because of water turbidity.

The physical stream characteristics were determined from topographic maps and aerial photographs as had occurred during the original DNR water typing in 1979. These characteristics are verified in the field utilizing the methods from the TFW Ambient Monitoring protocols (NWIFC, 1994) for determining channel bankfull widths and wetted widths, as well as the DNR Forest Practices Handbook (DNR, 1994) for calculating gradient. Channel length and bankfull width are measured by a hip-chain and tape measure, respectively. Length and width are typically measured to the nearest 1/10th meter. Stream gradient is measured by a hand-held clinometer at 25 meter stations and averaged, and pool depth is measured with a stadia rod from the deepest part of the pool to the water surface. Gradient is measured to the nearest 1 percent and pool depth to the nearest 1/10th meter. Flood plain connectivity is determined by measuring the lineal meters of road adjacent to one or both sides of a stream segment, and dividing by the length of the stream segment to generate a percent reduction in connectivity. Width-to-depth ratio is calculated by dividing the bankfull width by the channel depth. Road density is obtained by measuring road lengths per stream sub-basin using a desktop GIS software product.

METHODS OF ANALYSIS

Surveyed reaches are assessed to whether the habitat is potentially used by each of the four salmon species identified previously, using the methods of the US Army Corps of Engineers (USACE 1998) for determining species utilization in the upper Green River. The USACE delineated specific stream segments in the upper Green River that provide habitat for coho, steelhead, fall chinook, and spring chinook. Thus, the segments where habitat surveys are conducted were grouped in accordance to respective species in which they serve. To this end, the quality of habitat pertaining to each of these salmon species can be evaluated.

An analysis of the stream survey data, as categorized by respective salmon use, is conducted to determine habitat condition in the respective WAUs. Applicable, collected data are typically quantified using a Watershed Analysis Stream Survey Program spreadsheet (Fox 1996). Habitat metrics can then analyzed using two methods. The first compares the indices of resource conditions for interpretation of field survey results and habitat analysis in accordance with the methodology specified for Watershed Analysis in the State of Washington (Washington Forest Practices Board [WFPB] 1997). The second method of analysis compares these indices with the National Marine Fisheries Service's Matrix of Pathways and Indicators for habitat function (NMFS 1995; NMFS 1998). These methods provide quantitative or descriptive guides that link critical input variables to the habitat requirements of salmon. By accomplishing this, the factors that limit salmon habitat can be identified.

Both the NFMS "Matrix of Pathways and Indicators" and the Washington State Watershed Analysis "Indices of Resource Conditions" compare observed stream habitat conditions to a standard numerical or narrative descriptions. Both systems group the observed habitat quality or quantity into three broad categories. The WFPB uses "poor", "fair", and "good" while the NMFS uses "Not Properly Functioning", "At Risk", and "Properly Functioning". As both systems use three tiers of habitat condition, one can compare the narrative rating of equivalent or roughly equivalent habitat parameters. For the purposes of this report, "poor" was considered equivalent to "not Properly Functioning" and "good" comparable to "Properly Functioning". As several of the Washington State "Indices of Resource Conditions" metrics are similar to those of the NMFS "Matrix of Pathways and Indicators", both were listed for the purpose of comparing methods.

Several habitat parameters of the NMFS Matrix of Pathways do not contain threshold criteria in which to determine a habitat condition. For example, "Holding Pools" by the WFPB definition, synonymous with "Pool Quality" by the NMFS matrix, define respective ratings of "Good" and "Properly Functioning" as having "sufficient" pools >1m deep. Terms such as "sufficient", "few", and "most" do not have threshold criteria in which to base a determination of whether or not it serves as functional habitat. For this reason, criteria were developed for the parameters that lack thresholds based on best professional judgement based on knowledge of life history requirements of salmonids utilizing these WAUs. Data, as available, were also used to support these determinations. The following criteria were developed for these habitat parameters:

RIPARIAN CONDITIONS

Riparian habitat conditions were used to assess potential sources of riparian wood recruitment, which is used in conjunction with the NMFS parameter of “LWD Quantity”. The condition of riparian habitat is estimated using the methods described in the Washington Forest Practices Board Manual for Conducting Watershed Analysis (1994 [revised in 1997]). This method determines the age, species, and density of riparian forest stands. Potential wood recruitment into streams is based on tree height (McDade et al. 1989), and coniferous wood has greater longevity in the channel than deciduous wood (Robison and Beschta, 1990). Thus, riparian stands were considered to contain “properly functional” recruitment conditions if they were comprised of conifer trees in an “old” seral stage, “At Risk” if riparian trees were comprised of mature conifer or deciduous species, and “Not Properly Functioning” if riparian trees were young, (deciduous or conifer). Any stand that is classified as “sparse” in terms of density, is considered to be “Not Properly Functioning”. Age classifications of “old” is defined as trees having a $\geq$20 inches diameter breast height (dbh), “mature” as trees having $\geq$12 and <20 inches dbh, and young as <12 inches dbh (WFPB 1997).

The frequency of deep (>1m) holding pools is likely intended for adult salmon during upstream migration and spawning. Thus, limits in the distance a salmon can swim prior to reaching the next “resting place” is a function of body size and adult salmonid metabolic requirements, or spawning density. Due to the variability in holding pool requirements and the paucity of studies that quantify this need, a threshold is determined through “best professional judgement” based on knowledge of salmon body-size and densities that use these WAUs. Thus in these watershed analyses, $\geq$4 pools >1m deep per 100 meters of stream length will constitute as “good” (WFPB) and “Properly Functioning”(NMFS), 2-4 pools per 100 meters as “fair” and “At Risk”, and <2 per 100 meters as “poor” and “Not Properly Functioning”.

Flood plain connectivity was assessed and ranked using the following criteria: 1) Severe reduction in connectivity: greater than 50 percent of the stream segment is confined by anthropogenically constructed features on at least one banks (e.g. roads, levees, railroad grades, etc.); 2) Reduced connectivity: between 10-50 percent of the stream segment is confined by anthropogenically constructed features on one or both banks; or 3) insignificant reduction in connectivity: less than 10 percent of the stream segment is confined by anthropogenically constructed features on one or both banks.

Off-channel habitats typically comprise the areas of slower water velocities, often associated with winter-rearing life histories. Lack of suitable off-channel habitats can adversely affect winter-rearing, and also summer-rearing salmonids. Studies that determine threshold quantities of off-channel habitat are unavailable, thus an estimate to these quantities was made based on best professional judgement and knowledge of life history requirements of salmonids utilizing these WAUs. Data, as available, were also used to support these determinations. The NMFS criteria has no specified quantities of off-channel habitat to meet “Properly Functioning condition”, although it makes reference to “few”, “some”, and “present”. To this end, off-channel habitat greater than 10 percent of the total channel surface area within the survey reach will be considered as “Properly Functioning”, 5-10 percent off-channel habitat will be considered as “At Risk”, and less than 5 percent will be considered as “Not Properly Functioning”.

SPAWNING GRAVEL

Salmonids require sufficient quantities of gravel of a size range for spawning and incubation. Such gravels are small enough to be readily excavated during redd construction, yet large enough to promote oxygenation and metabolic waste removal through flow permeability. The NMFS criteria specify that gravel or cobble must be dominant with clear interstitial spaces in order to qualify as “Properly Functioning”. To this end, stream reaches having a frequency of occurrence of 50 percent or greater of gravel and cobble will be considered as “Properly Functioning”, 25 to ≤50 percent cobble/gravel will be considered “At Risk”, and <25 percent cobble/gravel “Not Properly Functioning”. Size definitions for gravel and cobble are presented in table Upper Green-4.

Table Upper Green-4. Size criteria Used to Classify Substrate in the Habitat Surveys in the Upper Green River and Sunday Creek WAUs.

Substrates
1- Sand, silt, clay. [<0.25” or <0.8 cm (smaller than pea size)]
2- Small Gravel [0.25”-1” or >0.8-2.5 cm (pea to golf-ball size)]
3- Large Gravel [>1” - 3” or >2.5-7.5 cm (golf-ball to baseball size)]
4- Small Cobble [>3”-6” or >7.5-15 cm (baseball to cantaloupe size)]
5- Large Cobble [>6”-12” or >15-30 cm (cantaloupe to basketball size)]
6- Small Boulders [>12”-40” or >30cm-1.0 m (basketball to car-tire size)]
7- Large Boulders [>40” or >1.0 m (greater than car-tire size)]
8- Bedrock

Also in accordance to the NMFS criteria, suitable substrate must have less than a certain degree of embeddedness (see Table 4). Embeddedness data are typically not collected during the surveys; however, data regarding the quantity of spawning gravel are shown where they were obtained for each reach. These data indicate the percent of total substrate that meets the life-history requirements for spawning and incubation such as flow velocity, particle size, the ability to excavate, etc.. This parameter, when coupled with the percent frequency of habitat units containing gravel/cobble as substrate, indicates how much of this substrate is embedded or does not possess the qualities of suitable spawning gravels. To this end, gravel/cobble substrates meeting the required frequency percentage as discussed above also occupy a minimum of 10 percent of the reach area. This is a combined percent of both anadromous and resident spawning area. For example, if greater than 50 percent of the habitat units contain gravel/cobble, the total spawning area for anadromous and resident species must be greater than 10 percent to qualify as “Properly Functioning”. If the area quantity is less than 10 percent, the gravel will be considered embedded or otherwise “non-spawnable”, and will be considered “Not Properly Functioning” regardless of the percent frequency of habitat units containing gravel/cobble. The methods and definitions for determining anadromous and resident spawning gravel are provided immediately below:

Anadromous: Within the habitat unit, the surface area of suitable spawnable gravel for large bodied or anadromous fish (gravel sizes ranging from 0.76 inches to 1.5 inches) will be determined and quantified. The site must have favorable characteristics for successful spawning, and incubation to emergence (i.e.: loose gravel, non-embedded, little evidence of scour, and sufficient flow depth and velocity).

Resident: Within the habitat unit, the surface area of suitable spawnable gravel for small bodied or resident fish (gravel sizes ranging from 0.25 inches to 0.75 inches) will be determined and quantified. This site must have favorable characteristics for successful spawning, incubation, and emergence (i.e.: loose gravel, little evidence of scour, and sufficient flow depth and velocity).

Table Upper Green-4. Some of the Habitat Rating Parameters used by the NMFS (NMFS 1995; NMFS 1998) and the Washington State Forest Practices Board (WFPB 1997) to Assess the Quality of Salmonid Habitat.			
HABITAT PARAMETER	**HABITAT QUALITY RATING**		
WFPB (1997)	**Poor**	**Fair**	**Good**
Percent Pool	<30%	30 - 40%	>40%
Pool Frequency	> 4 channel widths/pool	2 - 4	< 2 channel widths/pool
LWD/BFW	< 1	1 – 2	>2
Key pieces/ BFW	<0.20	0.20 - 0.50	>0.50
Holding Pools	Few pools/km (> 1 m deep)		Sufficient pools/km (> 1 m deep)
% wood cover in pools	Most pools 0-5%	Most pools 6-20%	Most pools >20%
Fine Sediment in spawning gravels (<0.85mm)	>17% fines	12-17% fines	<12% fines
NMFS (1995, 1998)	**Not Properly Functioning**	**At Risk**	**Properly Functioning**
Temperature	>60°F (spawning) >64°F (migration & rearing)	57-60°F(Spawning) 57-64°F (migration & rearing)	50-57°F
Fine Sediment in spawning gravels (<0.85mm)	>17% fines	12-17% fines	<11% fines
Physical Barriers	Any man-made barriers present in watershed do not allow upstream and/or downstream fish passage at a normal range of flows	Any man-made barriers present in watershed do not allow upstream and/or downstream fish passage at a base/low flows or at normal high flow conditions	Any man-made barriers present in watershed allow upstream and/or downstream fish passage at all flows
Substrate	Bedrock, sand, silt or small gravel dominant, or if gravel and cobble dominant, embeddedness > 30%.	Gravel and cobble is subdominant, or if dominant, embeddedness 20-30%	Dominant substrate is gravel or cobble (interstitial spaces clear), or embeddedness < 20%
Large Woody Debris			
Quantity	Does not meet standards for Properly Functioning and lack potential recruitment	Meets standards for Properly Functioning, but lacks potential sources of woody debris to maintain that standard	>80 piece/mile > 24" diameter and >50 ft length and adequate sources of woody debris recruitment in the riparian areas
Frequency of LWD by channel width	Does not meet standards for Properly Functioning and lack potential recruitment	Meets standards for Properly Functioning, but lacks potential sources of woody debris to maintain that standard	2.44-2.04 pieces/bankfull channel width for streams 13-62 ft. wide, respectively.
Volume of LWD per piece by channel width	Does not meet standards for Properly Functioning and lack potential recruitment	Meets standards for Properly Functioning, but lacks potential sources of woody debris to maintain that standard	0.25-3.70 m^3/piece for streams 13 ft.-62 ft. wide

Stream Habitat Elements Pool Frequency Channel width Pools/mi. 5 (feet) 184 (pools) 10 96 15 70 20 56 25 47 50 26 75 23 100 18	Does not meet pool frequency standards	Meets pool frequency standards, but large woody debris recruitment inadequate to maintain over time	Meet pool frequency standards
Pool Quality	no deep pools (>1 meter) and inadequate cover/temperature, major reduction of pool volume by fine sediment	Few deeper pools (>1 meter) present or inadequate cover/temperature, moderate reduction of pool volume by fine sediment	Pools> meter deep (holding pools) with good cover and cool water, minor reduction of pool volume by fine sediment
Off-channel habitat	Few or no backwaters, no off-channel ponds	Some backwaters and high energy side channels	Backwater with cover, and low energy off-channel areas
Channel & Watershed Conditions: Width/Depth Ratio	>12	10-12	<10
Floodplain Connectivity	Severe reduction in hydrologic connectivity between off-channel, wetland, floodplain and riparian areas; wetland extent drastically reduced, riparian vegetation/succession altered significantly, and channel degradation apparent	Reduced linkage of wetland, floodplains and riparian areas to main channel; overbank flows are reduced relative to historic frequency, as evidenced by moderate degradation of wetland function, riparian vegetation/succession	Off-channel areas are frequently hydrologically linked to main channel; overbank flows occur and maintain wetland functions, riparian vegetation and succession
Road Density & location	< 2mi/mi^2, no valley bottom roads	2-3 mi/mi^2, some valley bottom roads	>3 mi/mi^2, many valley bottom roads

Table Upper Green-5 presents estimated specific area recommendations required for successful anadromous salmonid spawning.

Table Upper Green-5. Average Observed Redd Area and Recommended Area per Pair Including Defended Area.

Species	Area Recommended per Pair (m²)
Summer/fall chinook	19
Spring Chinook	13
Coho	11
Steelhead	11

Source: Bjorn and Reiser 1991.

After assessing the quality of salmon habitat for each of the four previously mentioned salmon species, the results are compared to the critical input variables for each life history stage to determine the habitat factors that potentially limit natural salmon production in the Sunday Creek and Upper Green River WAUs.

INFORMATION SOURCES

Information is collected from various sources: USFS stream surveys; Tacoma Public Utilities (TPU) stream flow data, water quality, and anecdotal information; the United States Geological Survey (USGS), the Washington Department of Natural Resources (DNR), the US Army Corps of Engineers (Corps), Washington Department of Fish and Wildlife (WDFW), aerial photos , and the U.S. Fish and Wildlife Service (USFW&S). Field surveys conducted by the fish, channel, and riparian module teams provide the required information not previously collected or available. Fish distribution data for salmonid species was provided by the WDFW Washington Rivers Information System (WARIS), WDFW Priority Habitat and Species list, Washington State Salmon and Steelhead Stock Index (SASSI) (WDFW and WWTIT 1994), and was supplemented by field observations by fisheries biologists.

UPPER GREEN RIVER AND SUNDAY CREEK WAUS

STREAM COURSE AND MORPHOLOGY

The Upper Green and Sunday Creek WAUs, are situated on the west side of the central Cascade Mountains divide, approximately 23 miles (34 km) east of Enumclaw, Washington and entirely within King County. The Green River is the largest water body within the two WAUs, followed by Sunday Creek. The Sunday Creek WAU can best be defined as beginning at its confluence with the Green River (at RM 84.2) and continues in a northeast direction for approximately 7.9 miles to the divide at Stampede Pass. The Sunday Creek WAU has numerous tributaries contribute an additional 29.5 linear miles of stream to the mainstem Sunday Creek (Williams 1975). The Green River WAU, can be defined as beginning at the confluence of the Green River (RM 84.2) with Sunday Creek, extending upstream to the headwaters of the Green River in the vicinity of Blowout Mountain (approximately 10 linear miles). Numerous tributaries contribute over 41 linear miles of stream to the drainage. The drainage basin of the combined Green River and Sunday Creek WAUs encompass 39,237 acres.

The base elevation of the Green River and Sunday Creek WAUs is approximately 1,700 feet (519 meters) at the confluence of Sunday Creek. The basins rise to the top of the Cascade divide with an average basin elevation of 5,400 ft (1,646m). Approximately 12 miles (19.5 kilometers (km)) downstream of the lower WAU boundary, the Green River discharges into Howard Hanson Reservoir, a flood control reservoir operated by the Army Corps of Engineers. Downstream of Howard Hanson Dam (HHD) (at RM 64.5) the Green River flows past the Tacoma Headworks Dam (at RM 61) and enters the Green River Gorge and flows west and eventually flows through the City of Auburn where it turns north and flows through the lower Green River valley and into Elliott Bay near West Seattle. The details of habitat downstream of HHD are contained elsewhere in this report.

SALMONID DISTRIBUTION

The known freshwater distribution of anadromous salmonids is depicted the report Appendix. There is no historical information concerning salmonid species distribution or abundance in the upper Green River and Sunday Creek WAUs. However, three is substantial anecdotal information that implies anadromous fish migrated upstream of the Tacoma Headworks Project prior to its completion in 1911. Anadromous access into the Upper Green River and Sunday Creek WAUs seem likely, since there are no natural or anthropogenic passage barriers located on the mainstem Green River downstream of the WAUs. Historically, adult salmonids were documented at the Tacoma Headworks Diversion Dam (Grette and Salo, 1986), and adults have been documented upstream of the diversion dam site (Riseland, 1913).

Currently, the salmonid species inhabiting the upper Green River and Sunday Creek WAUs include chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), resident and anadromous (steelhead) rainbow trout (*O. mykiss*), cutthroat trout (*O. clarki*), and mountain whitefish (*Prosopium williamsonni*). Currently, only anadromous steelhead adults are passed upstream of the Tacoma Headworks Project and HHD. Spawning steelhead adults have been observed in the Green River as far upstream as RM 83.5 but they have not been observed in these WAUs. Juvenile steelhead, chinook and coho salmon have been released as hatchery plants into numerous streams in these WAUs and are depicted in Appendix B. Mountain whitefish, cutthroat and resident rainbow trout are known to inhabit the primary tributaries. As of the date of this report there are no reported observations of bull trout (*Salvalinus confluentus*) within the Upper Green River or Sunday Creek WAUs (Plum Creek Timber Company, 1994).

There are known resident trout populations in the Upper Green River and Sunday Creek WAUs that include rainbow and cutthroat. These species have a wide distribution, but since no formal inventory has been done, an exact distribution and abundance estimate cannot be determined. Adfluvial trout populations have been observed throughout the lower portions of the Green River and Sunday Creek in the WAUs. Resident trout are found in most of the major Green River and Sunday Creek tributaries and extend into tributaries classified as “Type 3” waters. Type 4 waters are also likely to contain resident trout populations where the stream gradient is less than 14 percent.

The mainstem Green River and all the primary tributary channels support resident rainbow and/or cutthroat trout. While not demonstrated, it is likely that hybridization between the two species has occurred (T. Cropp, WDFW, pers. comm.). Trout in reaches of isolated high-gradient streams are often segregated from other strains by passage barriers, although dispersal by downstream migration frequently occurs. The mainstem Green River, support a population of cutthroat trout that attain lengths of 20 inches (T. Cropp, WDFW, pers. comm.). These large and mature fish may represent a stock of adfluvial cutthroat that have matured in the reservoir and ascend the streams to spawn. Spawning activity of the adfluvial strains of trout are believed to occur primarily in the mainstem Green River and in the lower reaches of the accessible tributaries (Wunderlich and Toal, 1992). The stream rearing habitat requirements for resident trout are similar to those of steelhead. As with all species of salmonids using the WAUs, relatively shallow, channel margin and pool habitat is important during the earliest stages of life soon after incubation.

HABITAT CONDITIONS

In the Upper Green River and Sunday Creek WAUs Watershed Analyses (WSA), a total of forty-seven segments were sampled and surveyed. Anecdotal evidence was noted between sample reaches to obtain inferences on channel character and habitat condition and whether or not the segment was representative of the surveyed. In those 47 segments, a total of 7,202 meters of channel were quantitatively surveyed. As a part of the WSA, an additional 5,800 meters of stream channel were walked, in which observations were made regarding the character of the segment and incorporated into descriptions for their respective channel classifications. This was conducted for the purpose to verify that the reaches surveyed are representative of the stream.

The classification of segments by salmon species for which it serves resulted in 24 segments for coho (3,652 meters of stream), 29 segments for steelhead (4,352 meters of stream), 6 segments for fall chinook (1,118 meters of stream), and 12 segments for spring chinook (1,742 meters of stream). The field metrics identified in the NMFS “Matrix of Pathways” were quantified for habitats utilized by each species.

The following discussion relates the existing quality of habitat in the upper Green and Sunday Creek WAUs for each species to their respective life history requirements. This is accomplished by evaluating the effects associated with each respective critical input variable, which often dictates habitat quality.

FALL CHINOOK HABITAT CONDITIONS

Information was reviewed from six survey reaches that covered 1,118 meters of stream channel. These six survey reaches represent 18.3 percent of the presumed fall chinook habitat available in the Green River and Sunday Creek WAUs as identified by the Army Corps of Engineers (1998). Overall, the quality of fall chinook habitat is rated as "Not Properly Functioning". The key parameters examined are identified in table Upper Green-6.

Table Upper Green-6. Examined Key Habitat Parameters for Fall Chinook Reaches in the Green River and Sunday Creek WAUs.

Parameter	Minimum	Maximum	Mean	SD	N=
Survey Reach Length (m)	100	218	186	43.0	6
BFW (m)	5.3	20.9	11.2	5.3	6
Bankfull Depth (m)	0.40	0.6	0.5	0.1	6
Gradient (%)	1.5	3.0	2.4	0.7	6
Elevation (m)	558	607	588	18.7	6
Pools/mile	22.2	80.5	41.7	27.1	6
Holding Pools/mile	0	48.3	18.7	16.7	6
Percent of all pools that are holding/pools per mile	0%	67	43.6	26.5	6
Off-channel Habitat	0	45	11.7	16.9	6
Riparian Species 1=conifer, 2=deciduous	1	2	1.7	0.52	6
Riparian Age 1=old, 2=mature, 3=young	2	3	2.7	0.52	6
Riparian density: 1=dense, 2=sparse	1	2	1.2	0.41	6
Percent wood cover in pools	0-5%	5-10%	4.5%	2.7%	5
Width/depth ratio	13.3	37.3	21.2	8.4	6
Occurrence of sand, silt, clay (%)	0	25	4.17	10.21	6
Occurrence of gravel, cobble (%)	10	90	57.38	32.37	6
Occurrence of boulder/bedrock (%)	0	90	38.00	36.46	6
Anadromous Spawning Area (%)	0	2	0.67	0.82	6
Percent fines	16	16	16	0	1
Temperature (F)	62.24	62.24	62.24	0	1
Canopy Closure (%)	0%	78%	16.2%	30.9%	6
Min. shade requirement (%)*	47%	51%	48.5%	1.5%	6
NMFS wood pieces/mile	0	29.5	4.92	12.06	6

* Source: WFPB 1998.

RIPARIAN HABITAT

Watershed Analysis found that the bulk of the riparian habitats in the Green River and Sunday Creek WAUs are generally dense, but young deciduous trees. This condition is insufficient as a new LWD supply to the stream channel and hence maintain or improve the associated habitat forming processes. This situation will likely not ameliorate until the riparian stands reach a size and age that would allow for sufficient size and number to restore instream LWD loadings to a more natural level. The riparian condition is currently considered to be "Not Properly Functioning" for fall chinook in four of the six reaches surveyed and "At Risk" in the remaining two. These ratings are due to: (1) the deciduous component of trees that dominate the assessed riparian reaches for fall chinook; and (2) the young age of the trees present in the riparian area.

The young tree age and large deciduous component are likely directly responsible for the scarcity of NMFS criteria LWD present in the stream channel. The quantity of LWD within the fall chinook reaches is insufficient to maintain many of the necessary habitat elements and habitat forming elements. Though pieces of wood are numerous, they are typically small. Only four pieces of wood were found that meet NMFS size criteria within the survey fall chinook reaches. This represents only 7.1 percent of the 56 pieces needed to be considered “Properly Functioning”. None of the reaches surveyed met NMFS criteria for wood quantity, nor are the channel adjacent stands considered to be adequate to maintain LWD recruitment processes in the near term. Thus, for fall chinook this yields a “Not Properly Functioning” assessment.

SUBSTRATE

WSA indicates that spawning gravels are in short supply throughout the reaches examined. Surveys indicate that a mean of 0.76 percent of the total surveyed stream channel was observed to contain potential suitable spawning substrate. Three of the six reaches surveyed were dominated by boulder/bedrock and the remaining three reaches were dominated by gravel/cobble with very little gravel distributed in areas that were deemed useful for fall chinook spawning. Overall, the paucity of suitable spawning gravels in the reaches surveyed are a limiting factor for fall chinook production and were rated as “Not Properly Functioning.”

Mass wasting and hillslope erosion was determined not to be a significant contributor to the overall levels of fine sediment produced in the Green River and Sunday Creek WAUs. Secondary sediment erosion from mass wasting scarps generally was below the 50 percent of the natural background sediment input cutoff point for a moderate hazard rating designation. There was one exception, the Pioneer Creek subbasin, where the estimated sediment yield is 57 percent of the background.

POOLS

Of the 24 reaches surveyed, the number of pools varied considerably. Using pool frequencies as calculated from the pool frequency regression curve, 16 of the 24 surveyed reaches do not meet NMFS criteria for “Properly Functioning” for pool frequency. When taken in the aggregate, the streams had roughly the required number of pools required to meet MNFS criteria as “Properly Functioning”. Cumulatively, the surveyed reaches had 26 pools in fall chinook reaches where 28.4 were to be expected. Two of the six reaches surveyed had more pools than required and overly compensated for the other four reaches that had far fewer than the required number of pools. However, despite the number of pools present, all of the reaches, including those that met NMFS pool criteria to be considered “Properly Functioning” are assigned an “At Risk” factor because of the inadequacy of the riparian zone to recruit LWD into the stream channel to form pools.

Approximately 44 percent of the pools surveyed met minimum depth requirements (>1 meter). The ability of the pools to provide cover and holding areas is further reduced by the pool in-water and overwater cover, again because of the lack of LWD. Pool quality was deemed insufficient to provide suitable habitat for fall chinook as was assigned an “At Risk” rating.

CHANNEL CONDITIONS

Reach specific and cumulative observations suggest that the stream channel has become shallow and wide. This may also be an influencing factor in decreased pool quality and adversely impacts the ability of the available habitat to successfully hold adult and rear juvenile salmonids. The mean width:depth ratio was 21.22. This indicates increased proportion of riffles and glides that leads to reduced high flow refugia and available over-winter rearing habitats, an increased water surface area exposed to solar radiation that in turn could lead to increased stream water temperatures. Additionally, the high width to depth ratio may influence fall chinook spawning through decreases in wetted stream areas with acceptable depths for spawning fall chinook. A designation of “Not Properly Functioning” was assigned to stream channel conditions because of the high width:depth ratio.

There are a number of barriers, primarily culverts, that prevent adult and juvenile access to tributaries in this subbasin. A detailed listing of known anthropogenic barriers in this subbasin are contained in the Barriers Chapter of this report. However, a comprehensive survey has not been initiated that lists all known anthropogenic barriers.

OFF CHANNEL HABITAT

Six reaches were surveyed for the quantity of off-channel habitat. Only one of these six reaches was ranked as “Properly Functioning” with 45 percent of the off-channel habitat in this reach skewed the mean value to 11.7 percent. However, this single reach is not representative of the other five stream reaches as noted by the high variability, which is illustrated by a standard deviation of 16.9 percent. Three of the six reaches are rated as “Not Properly Functioning” while the others are rated as “At Risk”. Overall, off-channel habitats are rated as “Not Properly Functioning” again due to the scarceness of LWD and the off-channel habitat forming processes associated with LWD.

WATER QUALITY

Water temperature was measured in one stream as 62.2 F, which would give a rating of “Not Properly Functioning”. A probable cause of elevated stream temperatures is that the mean canopy closure is only 24.0 percent while 41.3 percent canopy coverage is required to meet shade standards (WFPB 1998) to avoid solar radiation and induced water temperature increases.

SPRING CHINOOK HABITAT

Information was reviewed from twelve (12) survey reaches that covered 1,742 meters of stream channel. These twelve survey reaches represent 16.6 percent of the presumed spring chinook habitat available in the Green River and Sunday Creek WAUs as identified by the Army Corps of Engineers (1998). The key parameters examined are identified in table Upper Green-7.

Table Upper Green-7. Examined Key Habitat Parameters for Spring Chinook Reaches in the Green River and Sunday Creek WAUs.					
Parameter	**Minimum**	**Maximum**	**Mean**	**SD**	**N=**
Survey Reach Length (m)	24	218	145	64.1	12
BFW (m)	4	21	10	438	12
Bankfull Depth (m)	0.4	1.5	1	0.4	12
Gradient (%)	1.5	5	2.5	0.4	12
Elevation (m)	558	723	635.4	58.4	12
Pools/mile	0	134.1	44.1	38.5	12
Holding Pools/mile	0	48.3	9.3	14.9	12
Percent of all pools that are holding/pools per mile	0%	67	26	30	10
Off-channel Habitat	0	45	1.3	16.2	9
Riparian Species 1=conifer, 2=deciduous	1	3	1.8	0.4	6
Riparian Age 1=old, 2=mature, 3=young	2	3	2.8	0.4	6
Riparian density: 1=dense, 2=sparse	1	2	1.2	0.4	6
Percent wood cover in pools	0.5%	5-10%	0-5%	---	9
Width/depth ratio	7.3	37.3	16.1	7.9	6
Occurrence of sand, silt, clay (%)	0	25	3.0	7.6	6
Occurrence of gravel, cobble (%)	10	100	69.1	30.4	6
Occurrence of boulder/bedrock (%)	0	90	27.80	32.4	6
Anadromous Spawning Area (%)	0	6	1.3	1.8	10
Percent fines	16	16	16	0	1
Temperature (F)	58.1	67.2	60.2	2.9	5
Canopy Closure (%)	0%	93%	20.7%	31.9%	12
Min. shade requirement (%)*	37%	51%	44.3%	5.1%	12
NMFS wood pieces/mile	0	257.6	27.3	73.8	12
* Source: WFPB 1998.					

RIPARIAN HABITAT

Watershed Analysis found that the bulk of the riparian habitats that could be utilized by spring chinook in the Green River and Sunday Creek WAUs are generally dense, but young deciduous trees. This condition is insufficient as a new LWD supply to the stream channel and hence maintain or improve the associated habitat forming processes. This situation will likely not ameliorate until the riparian stands reach a size and age that would allow for sufficient size and number to restore instream LWD loadings to a more natural level. The riparian condition is currently considered to be “Not Properly Functioning” for spring chinook in ten of the twelve reaches surveyed and “At Risk” in the remaining two. These ratings are due to: (1) the deciduous component of trees that dominate the assessed riparian reaches for fall chinook; and (2) the young age of the trees present in the riparian area.

The young tree age and large deciduous component are likely directly responsible for the scarcity of NMFS criteria LWD present in the stream channel. The quantity of LWD within the spring chinook reaches is insufficient to maintain many of the necessary habitat elements and habitat forming elements. None of the reaches surveyed met NMFS criteria for wood quantity, nor are the channel adjacent stands considered to be adequate to maintain LWD recruitment processes in the near term. Thus, for spring chinook this yields a “Not Properly Functioning” assessment.

SUBSTRATE

WSA indicates that spawning gravels are in short supply throughout the reaches examined. Surveys indicate that a mean of 1.3 percent of the total surveyed stream channel was observed to contain potential suitable spawning substrate. Individual reaches also reflected poor spawning gravel quality. Eleven of the twelve reaches were rated as “Not Properly Functioning” due to inadequate area of spawnable gravels. Boulder/bedrock was the dominant feature in four reaches while gravel/cobble dominated the remaining eight. The gravel/cobble reaches contained very little gravel distributed in areas that could be utilized by spawning spring chinook. Only one reach (mainstem Green River at RM 86.4) that contained 6 percent spawning gravel was considered “At Risk”, the remaining reaches were all considered to be “Not Properly Functioning”. Overall, the paucity of suitable spawning gravels in the reaches surveyed are a limiting factor for spring chinook production and were rated as “Not Properly Functioning”.

Mass wasting and hillslope erosion was determined not to be a significant contributor to the overall levels of fine sediment produced in the Green River and Sunday Creek WAUs. Secondary sediment erosion from mass wasting scarps generally was below the 50 percent of the natural background sediment input cutoff point for a moderate hazard rating designation. There was one exception, the Pioneer Creek subbasin, where the estimated sediment yield is 57 percent of the background.

POOLS

Overall, the spring chinook reaches surveyed had 85 percent of the required number of pools to meet NMFS as “Properly Functioning”. However, the poor quality of the pools and the inadequate stream adjacent riparian reserves strongly suggest that a lower habitat quality rating be assigned than consideration of pool frequency alone would suggest.

Of the twelve reaches surveyed, the number of pools varied considerably. Using pool frequencies as calculated from the pool frequency regression curve, nine of the twelve surveyed reaches do not meet NMFS criteria for “Properly Functioning” for pool frequency. When taken in the aggregate, the streams had roughly the required number of pools required to meet MNFS criteria as “Properly Functioning.” Cumulatively, the surveyed reaches had 41 pools in spring chinook reaches where 48 were to be expected. Individually, nine of the twelve reaches had a pool deficit and are rated as “Not Properly Functioning”. However, on a system wide basis, these numerical deficiencies were almost compensated by reaches containing more pools than required. However, despite the number of pools present, all of the reaches, including those that met NMFS pool criteria to be considered “Properly Functioning” are assigned an “At Risk” factor because of the inadequacy of the riparian zone to recruit LWD into the stream channel to form pools. Without LWD inputs into the stream channel it should be expected that there will be a net decrease over time of pool quality and pool numbers.

Approximately 26 percent of the pools surveyed met minimum depth requirements (>1 meter). The ability of the pools to provide cover and holding areas is further reduced by the pool in-water and overwater cover, again because of the lack of LWD. Cover in all pools was considered poor, with a mean coverage in the 0-5 percent range. Pool quality was deemed insufficient to provide suitable habitat for spring chinook as was assigned an “At Risk” rating.

CHANNEL CONDITIONS

Reach specific and cumulative observations suggest that the stream channel has become shallow and wide. This may also be an influencing factor in decreased pool quality and adversely impacts the ability of the available habitat to successfully hold adult and rear juvenile salmonids. The mean width:depth ratio was 16.1. This indicates increased proportion of riffles and glides that leads to reduced high flow refugia and available over-winter rearing habitats, an increased water surface area exposed to solar radiation that in turn could lead to increased stream water temperatures. Additionally, the high width to depth ratio may influence fall chinook spawning through decreases in wetted stream areas with acceptable depths for spawning fall chinook.

Individually, two of the twelve surveyed reaches met the NMFS criteria to be defined as “Properly Functioning” while two were “At Risk” and the remaining eight were “Not Properly Functioning”.

A designation of “Not Properly Functioning” was assigned to stream channel conditions because of the high width:depth ratio.

OFF CHANNEL HABITAT

Nine reaches were surveyed for the quantity of off-channel habitat. Only two of these nine reaches was ranked as “Properly Functioning”, three were ranked as “At Risk” and five at “Not Properly Functioning”. Two reaches with exceptionally large percentages of off-channel rearing (45 percent and 32 percent) skewed the mean value to 11.3 percent. However, this single reach is not representative of the other five stream reaches as noted by the high variability, which is illustrated by a standard deviation of 16.2 percent. Overall, off-channel habitats are rated as “Not Properly Functioning” again due to the scarceness of LWD and the off-channel habitat forming processes associated with LWD.

WATER QUALITY

Water temperature was measured in one stream as 60.2 F, which would give a rating of “Not Properly Functioning”. A probable cause of elevated stream temperatures is that the mean canopy closure is only 20.7 percent while 44 percent canopy coverage is required to meet shade standards (WFPB 1998) to avoid solar radiation and induced water temperature increases.

COHO

Information was reviewed from 24 reaches that were surveyed that were considered to support coho salmon. This represented an area covering 3,652 meters of stream channel and further represents approximately 17.8 percent of the presumed coho habitat in the Green River and Sunday Creek WAUs. Key parameters of the coho habitat survey are presented in table Upper Green-8 below.

Table Upper Green-8. Examined Key Habitat Parameters for Coho Reaches in the Green River and Sunday Creek WAUs.					
Parameter	**Minimum**	**Maximum**	**Mean**	**SD**	**N=**
Survey Reach Length (m)	24	300	152.0	77.0	24
BFW (m)	4	38	13.2	8.3	24
Bankfull Depth (m)	0.37	2.5	0.98	0.66	24
Gradient (%)	1.0	6.0	2.6	1.4	24
Elevation (m)	529	723	612	59.7	24
Pools/mile	0	134.1	37.0	32.6	24
Holding Pools/mile	0	48.3	9.2	11.8	24
Percent of all pools that are holding/pools per mile	0	100	35	35	21
Off-channel Habitat	0	49	10.2	16.6	16
Riparian Species 1=conifer, 2=deciduous	1	2	1.8	0.4	23
Riparian Age 1=old, 2=mature, 3=young	2	3	2.9	0.3	23
Riparian density: 1=dense, 2=sparse	1	2	1.2	0.4	23
Percent wood cover in pools	0-5%	5-10%	0-5%	2.7	16
Width/depth ratio	6.0	37.3	15.2	6.6	24
Occurrence of sand, silt, clay (%)	0	25	3.2	7.6	24
Occurrence of gravel, cobble (%)	0	100	66.7	32.4	24
Occurrence of boulder/bedrock (%)	0	100	24.3	32.0	24
Anadromous Spawning Area (%)	0	13.0	2.1	3.1	21
Percent fines	6	16	11.0	7.1	2
Temperature (F)	57.2	62.24	59.1	2.0	5
Canopy Closure (%)	0	93	21.3	25.7	24
Min. shade requirement (%)*	20%	54	42.8	9.6	24
NMFS wood pieces/mile	0	257	30.2	65.7	24
* Source: WFPB 1998.					

RIPARIAN HABITAT

Watershed Analysis found that the bulk of the riparian habitats that could be utilized by coho in the Green River and Sunday Creek WAUs are generally dense, but consist of young deciduous trees. This condition is insufficient as a new LWD supply to the stream channel and hence maintain or improve the associated habitat forming processes. This situation will likely not ameliorate until the riparian stands reach a size and age that would allow for sufficient size and number to restore instream LWD loadings to a more natural level. The riparian condition is currently considered to be "Not Properly Functioning" for coho in 20 of the 23 reaches surveyed and "At Risk" in the remaining three. These ratings are due to: (1) the deciduous component of trees that dominate the assessed riparian reaches for fall chinook; and (2) the young age of the trees present in the riparian area. The condition of the riparian habitat is currently not sufficient in the near term to provide suitable amounts and quality of LWD to the stream channel to maintain associated habitat and other ecological forming processes. Without large coniferous trees for recruitment and retention, the existing level of coho production should be expected to decline.

The mean pieces of WSA size wood (>10 centimeters diameter, >2 meters length) per channel width was 3.0. A rating of good is assigned to stream channels with at least 2.0 pieces per channel width (WFPB 1997). However, this good rating is strongly influenced by one reach in the mainstem Green River (RM85.8) where a segment long log jam contained an average of 34 pieces per channel width. In the absence of this log jam, the number of wood pieces per channel width over the surveyed habitat would be 1.7, yielding a rating of “Fair” under WSA standards. This patchy distribution of wood in the stream channel is indicated by the standard deviation of 7.1 pieces per channel width.

WSA key pieces are also below the desired target numbers, averaging only 0.02 pieces per channel width. This represents less than 10 percent of the target goal of 0.3 pieces per channel width.

When NMFS criteria are applied, only 56 pieces of wood were identified within the reaches surveyed for coho salmon. This represents only 31 percent of the target level of 181 pieces required to be considered “Properly Functioning” by NMFS. This yields an overall habitat rating as “Not Properly Functioning”.

SUBSTRATE

WSA indicates that spawning gravels are in short supply and inadequate for adult coho salmon spawning throughout the reaches examined. Surveys indicate that a mean of 2.1 percent of the total surveyed stream channel was observed to contain potential suitable spawning substrate where the desired threshold is 10 percent. Individual reaches also reflected poor spawning gravel quality. Twenty of the twenty-one reaches were rated as “Not Properly Functioning” due to inadequate area of spawnable gravels. The gravel/cobble reaches category dominated (67 percent) the reaches but contained very little gravel distributed in areas that could be utilized by spawning coho. Only one reach (mainstem Green River at RM 86.4) that contained 13 percent spawning gravel was considered “Properly Functioning”, while the remaining reaches were all considered to be “Not Properly Functioning”. Overall, the paucity of suitable spawning gravels in the reaches surveyed are a limiting factor for coho production and were rated as “Not Properly Functioning”.

Mass wasting and hillslope erosion was determined not to be a significant contributor to the overall levels of fine sediment produced in the Green River and Sunday Creek WAUs. Secondary sediment erosion from mass wasting scarps generally was below the 50 percent of the natural background sediment input cutoff point for a moderate hazard rating designation. There was one exception, the Pioneer Creek subbasin, where the estimated sediment yield is 57 percent of the background.

Fine sediment sampled in two reaches was measured at 6 percent and 16 percent. A mean of fines of 11.0 percent is considered to be “Properly Functioning” (NMFS).

POOLS

Overall, the coho reaches surveyed had 81 percent of the required number of pools to meet NMFS as “Properly Functioning”. However, the poor quality of these pools and the inadequate stream adjacent riparian reserves strongly suggest that a lower habitat quality rating be assigned than consideration of pool frequency alone would suggest.

Of the 24 reaches surveyed, the number of pools varied considerably. Using pool frequencies as calculated from the pool frequency regression curve, 16 of the 24 surveyed reaches do not meet

NMFS criteria for “Properly Functioning” for pool frequency. When taken in the aggregate, the streams had roughly the required number of pools required to meet MNFS criteria as “Properly Functioning”. Cumulatively, the surveyed reaches had 75 pools in coho reaches where 91 were to be expected. However, on a system wide basis, these numerical deficiencies were almost compensated by reaches containing more pools than required. However, despite the number of pools present, all of the reaches, including those that met NMFS pool criteria to be considered “Properly Functioning” are assigned an “At Risk” factor because of the inadequacy of the riparian zone to recruit LWD into the stream channel to form pools. Without LWD inputs into the stream channel it should be expected that there will be a net decrease over time of pool quality and pool numbers.

Approximately 35 percent of the pools surveyed met minimum depth requirements (>1 meter). The ability of the pools to provide cover and holding areas is further reduced by the pool in-water and overwater cover, again because of the lack of LWD. Cover in all pools was considered poor, with a mean coverage in the 0-5 percent range. Pool quality was deemed insufficient to provide suitable habitat for spring chinook as was assigned an “At Risk” rating.

CHANNEL CONDITIONS

Reach specific and cumulative observations suggest that the stream channel has become shallow and wide. This may also be an influencing factor in decreased pool quality and adversely impacts the ability of the available habitat to successfully hold adult and rear juvenile salmonids. The mean width:depth ratio was 15.2. This indicates increased proportion of riffles and glides that leads to reduced high flow refugia and available over-winter rearing habitats, an increased water surface area exposed to solar radiation that in turn could lead to increased stream water temperatures. Additionally, the high width to depth ratio may influence coho spawning through decreases in wetted stream areas with acceptable depths for spawning coho.

Individually, three of the 24 surveyed reaches met the NMFS criteria to be defined as “Properly Functioning” while five were “At Risk” and the remaining 18 were “Not Properly Functioning”.

A designation of “Not Properly Functioning” was assigned to stream channel conditions because of the high width:depth ratio.

OFF CHANNEL HABITAT

The quantity of off-channel habitat is cumulatively 10.2 percent of the total wetted area and is considered to be “Properly Functioning”. However, on an individual basis, only four of the 16 reaches surveyed achieve a rating of “Properly Functioning”.

WATER QUALITY

Water temperature as measured in five streams averaged 59.1 F giving an overall rating of “At Risk”. A probable cause of elevated stream temperatures is that the mean canopy closure is only 20.5 percent while 42 percent canopy coverage is required to meet shade standards (WFPB 1998) to avoid solar radiation and induced water temperature increases.

STEELHEAD

Information was reviewed from 29 surveyed reaches that were considered to support steelhead. This represented an area covering 4,352 meters of stream channel and further represents approximately 20.3 percent of the presumed steelhead habitat in the Green River and Sunday Creek WAUs. Key parameters of the steelhead habitat survey are presented in table Upper Green-9 below.

Table Upper Green-9. Examined Key Habitat Parameters for Steelhead Reaches in the Green River and Sunday Creek WAUs.

Parameter	Minimum	Maximum	Mean	SD	N=
Survey Reach Length (m)	24	300	150.1	77.7	29
BFW (m)	4.0	38.0	13.0	7.8	29
Bankfull Depth (m)	0.4	2.5	1.1	0.7	29
Gradient (%)	1.0	11.0	3.0	2.0	29
Elevation (m)	529	838	635.7	78.1	29
Pools/mile	0	134.1	40	34.5	29
Holding Pools/mile	0	48.3	8.6	11.7	29
Percent of all pools that are holding/pools per mile	0	100	29	34	26
Off-channel Habitat	0	49	9.5	15.8	18
Riparian Species 1=conifer, 2=deciduous	1	2	1.8	0.4	28
Riparian Age 1=old, 2=mature, 3=young	2	3	2.9	0.3	28
Riparian density: 1=dense, 2=sparse	2	1	1.1	0.4	28
Percent wood cover in pools	0-5%	5-10%	0-5%	N/A	18
Width/depth ratio	6.0	37.3	14.3	6.4	29
Occurrence of sand, silt, clay (%)	0	25	2.9	7.1	28
Occurrence of gravel, cobble (%)	0	100	61.5	33.5	28
Occurrence of boulder/bedrock (%)	0	100	34.2	36.3	28
Anadromous Spawning Area (%)	0	13	2	2.9	25
Percent fines	6	16	11.0	7.1	2
Temperature (F)	57.2	62.2	59.6	2.2	5
Canopy Closure (%)	0	93.0	24.0	25.3	29
Min. shade requirement (%)*	20	54	41.3	9.4	29
NMFS wood pieces/mile	0	257.6	26.6	60.3	29
* Source: WFPB 1998.					

RIPARIAN HABITAT

Watershed Analysis found that the bulk of the riparian habitats that could be utilized by steelhead in the Green River and Sunday Creek WAUs are generally dense, but consist of young deciduous trees. This condition is insufficient as a new LWD supply to the stream channel and hence maintain or improve the associated habitat forming processes. This situation will likely not ameliorate until the riparian stands reach a size and age that would allow for sufficient size and number to restore instream LWD loadings to a more natural level. The riparian condition is currently considered to be "Not Properly Functioning" for steelhead in 25 of the 28 reaches surveyed and "At Risk" in the remaining three. These ratings are due to: (1) the deciduous component of trees that dominate the assessed riparian reaches for steelhead; and (2) the young age of the trees present in the riparian area. The condition of the riparian habitat is currently not sufficient in the near term to provide suitable amounts and quality of LWD to the stream channel to maintain associated habitat and other ecological forming processes. Without large coniferous trees for recruitment and retention, the existing level of steelhead production should be expected to decline.

The mean pieces of WSA size wood (>10 centimeters diameter, >2 meters length) per channel width was 2.8. A rating of good is assigned to stream channels with at least 2.0 pieces per channel width (WFPB 1997). However, this good rating is strongly influenced by one reach in the mainstem Green River (RM85.8) where a segment long log jam contained an average of 34 pieces per channel width. In the absence of this log jam, the number of wood pieces per channel width over the surveyed habitat would be 1.7, yielding a rating of “Fair” under WSA standards. This patchy distribution of wood in the stream channel is indicated by the standard deviation of 7.0 pieces per channel width.

WSA key pieces are also below the desired target numbers, averaging only 0.03 pieces per channel width. This represents less than 20 percent of the target goal of 0.15 pieces per channel width.

When NMFS criteria are applied, only 59 pieces of wood were identified within the reaches surveyed for steelhead. This represents only 27.3 percent of the target level of 216 pieces required to be considered “Properly Functioning” by NMFS. Individually, two of the 29 reaches met NMFS wood requirement criteria. However, due to the young deciduous conditions adjacent to the stream channel, potential wood recruitment sources will be unable to maintain or improve the necessary wood loadings. This yields an overall habitat rating as “Not Properly Functioning.”

SUBSTRATE

WSA indicates that spawning gravels are in short supply and inadequate for adult steelhead spawning throughout the reaches examined. Surveys indicate that a mean of 2.0 percent of the total surveyed stream channel was observed to contain potential suitable spawning substrate where the desired threshold is 10 percent. Individual reaches also reflected poor spawning gravel quality. Twenty-four of the twenty-five reaches were rated as “Not Properly Functioning” due to inadequate area of spawnable gravels. The gravel/cobble reaches category dominated 17 of the 28 reaches (60.7 percent) but contained very little gravel distributed in areas that could be utilized by spawning steelhead. Only one reach (mainstem Green River at RM 86.4) that contained 13 percent spawning gravel was considered “Properly Functioning”, while the remaining reaches were all considered to be “Not Properly Functioning”. Overall, the paucity of suitable spawning gravels in the reaches surveyed are a limiting factor for steelhead production and were rated as “Not Properly Functioning”.

Mass wasting and hillslope erosion was determined not to be a significant contributor to the overall levels of fine sediment produced in the Green River and Sunday Creek WAUs. Secondary sediment erosion from mass wasting scarps generally was below the 50 percent of the natural background sediment input cutoff point for a moderate hazard rating designation. There was one exception, the Pioneer Creek subbasin, where the estimated sediment yield is 57 percent of the background.

POOLS

Overall, the steelhead reaches surveyed had more than the required number of pools to meet NMFS as “Properly Functioning”. However, the poor quality of these pools and the inadequate stream adjacent riparian reserves strongly suggest that a lower habitat quality rating be assigned than consideration of pool frequency alone would suggest.

Of the 29 reaches surveyed, the number of pools varied considerably. Cumulatively, using pool frequencies as calculated from the pool frequency regression curve, the reaches contained 98 pools and exceeded the NMFS requirement of 90 pools. However, on an individual basis, 18 of the 29 surveyed reaches do not meet NMFS criteria for “Properly Functioning” for pool frequency and in fact would be considered as “Not Properly Functioning”. However, on a system wide basis, these numerical deficiencies were almost compensated by reaches containing more pools than required. Despite the number of pools present, all of the reaches, including those that met NMFS pool criteria to be considered “Properly Functioning” are assigned an “At Risk” factor because of the inadequacy of the riparian zone to recruit LWD into the stream channel to form pools. Without LWD inputs into the stream channel it should be expected that there will be a net decrease over time of pool quality and pool numbers.

Approximately 29 percent of the pools surveyed met minimum depth requirements (>1 meter). The ability of the pools to provide cover and holding areas is further reduced by the pool in-water and overwater cover, again because of the lack of LWD. Cover in all pools was considered poor, with a mean coverage in the 0-5 percent range. Pool quality was deemed insufficient to provide suitable habitat for spring chinook as was assigned an “At Risk” rating.

CHANNEL CONDITIONS

Of the 29 surveyed reaches for steelhead, only five met the NMFS criteria for “Properly Functioning”, eight can be described as “At Risk” and the remaining sixteen as “Not Properly Functioning”. Reach specific and cumulative observations suggest that the stream channel has become shallow and wide. This may also be an influencing factor in decreased pool quality and adversely impacts the ability of the available habitat to successfully hold adult and rear juvenile salmonids. The mean width:depth ratio was 14.3, where a target of less than 10 is required to meet favorable channel conditions. This indicates increased proportion of riffles and glides that leads to reduced high flow refugia and available over-winter rearing habitats, an increased water surface area exposed to solar radiation that in turn could lead to increased stream water temperatures. Additionally, the high width to depth ratio may influence steelhead spawning through decreases in wetted stream areas with acceptable depths for spawning steelhead.

A designation of “Not Properly Functioning” was assigned to stream channel conditions because of the high width:depth ratio.

OFF CHANNEL HABITAT

The quantity of off-channel habitat is cumulatively 9.5 percent of the total wetted area and is considered to be “At Risk”. However, on an individual basis, only four of the 18 reaches surveyed achieve a rating of “Properly Functioning”. Therefore, natural production of steelhead is considered to be limited by the lack of off-channel rearing opportunities in the Green River and Sunday Creek WAUs.

WATER QUALITY

Water temperature as measured in five streams averaged 59.6 F giving an overall rating of "At Risk" for juvenile steelhead rearing and adult summer steelhead that might be migrating, holding or spawning in these reaches. A probable cause of elevated stream temperatures is that the mean canopy closure is only 24.0 percent while 41.3 percent canopy coverage is required to meet shade standards (WFPB 1998) to avoid solar radiation and induced water temperature increases.

SUBSTRATE

The quality of spawning habitat is dictated by the abundance of spawnable gravels, adjacent cover, and riparian shade. This is in turn affected by coarse and fine sediment, large wood, riparian vegetation, and flow. Spawning gravel is considered to be "Not Properly Functioning" for any of the salmon species present. A number of factors could be contributing to this alone or collectively. This could be a result influenced by the lack of LWD that serves to trap gravels, which is at levels considered to be "Not Properly Functioning" (NMFS) or poor (WFPB). Also, the cover component in pools, important for salmonid spawning may also be limiting due to is present rating of "poor" (WFPB). Furthermore, the stream temperatures for spawning is considered to be "At Risk" (NMFS) for all species except fall chinook, in which this condition is considered to be "Not Properly Functioning" (NMFS). The influence of the riparian area is likely to contribute to the lack of large wood, elevated stream temperatures, and lack of cover. The riparian condition is considered to be "Not Properly Functioning" (NMFS) for all the aforementioned salmon species.

Fine sediment is considered to be "At Risk" for coho and steelhead. Fine sediment can inhibit redd excavation and incubation, as noted previously. Fine sediment does not currently limit fall and spring chinook spawning, in which this metric is considered to be Properly Functioning (NMFS).

Mass wasting and hillslope erosion was determined not to be a significant contributor to the overall levels of fine sediment produced in the Green River and Sunday Creek WAUs. Secondary sediment erosion from mass wasting scarps generally was below the 50 percent of the natural background sediment input cutoff point for a moderate hazard rating designation. There was one exception, the Pioneer Creek subbasin, where the estimated sediment yield is 57 percent of the background.

SUMMARY

In summary, anadromous salmonid spawning habitat is limited by 1) the lack of suitable spawning gravels, 2) the lack of cover in pools, and 3) at times by elevated water temperatures. These components are influenced by the loss of LWD, which is lacking in the system, a poor riparian condition, which is also "Not Properly Functioning" condition, and fine sediment for coho and steelhead spawning habitat, which is considered to be "At Risk".

Summer rearing habitat requires the use of large deep pools and off-channel areas that provide adequate water flow, ample cover, cool water temperatures, optimal feeding opportunities, inter- and intra- species interaction, and opportunities, depending on needs, to hold in slow or fast moving water. The factors that influence summer-rearing habitat are channel form, gradient, small and large in-stream wood, canopy closure, and food input. Riparian vegetation and in-stream wood provide cover and channel complexity during this phase. Pool area and pool quality, large wood, cover in pools, and riparian vegetation are considered to be "Not Properly Functioning" for coho, steelhead, fall and spring chinook, and thus are likely to limit summer rearing opportunities and success.

Winter rearing areas provide stable and non-turbid stream flow during storm events. This habitat also must provide adequate flow, cover, and temperatures that facilitate metabolic conservation. The majority of the confined streams in the Upper Green River and Sunday Creek WAUs have only limited ability to form off-channel and wetland areas due to their confinement by road and railway grades. In the absence of side channels, salmonids typically are forced to over-winter in the substrate and under the protection of wood. Off-channel habitat is in short supply for coho and steelhead, and considered to be "At Risk"; however, this habitat is considered to be "Properly Functioning" for fall and spring chinook (NMFS).

The "At Risk" condition of winter-rearing habitat for coho and steelhead in the upper Green and Sunday Creek WAUs is likely caused by several factors. When LWD abundance is compared to NMFS criteria the large logs that contribute to off-channel habitat formation are in short supply and thus are likely to limit winter rearing. The riparian canopy, which helps to maintain ambient stream temperatures at night, is also in a "Not Properly Functioning" condition (NMFS). Interstitial substrate is adversely affected by overloading the stream with fine sediment, as indicated by the "At Risk" rating for fine sediment (NMFS), which reduces the available winter rearing habitat.

To summarize, winter-rearing habitat is limited for coho and steelhead in the Green and Sunday Creek WAUs. The lack of LWD is likely a limiting factor that contributes to the formation of these habitats. The quality of winter-rearing habitat is also reduced by the inadequate riparian condition, the elevated levels of fine sediment, and the lack of cover in pools.

Cover is an important component for juvenile salmonid migration, as is a normal temperature regime. LWD, which helps to provide cover to protect salmonids from predators, direct sunlight, and high water temperatures, is in short supply for all the species considered in this analysis (NMFS). The riparian vegetation, which provides shade and cover to the stream, is also considered to be lacking (NMFS). The elevated stream temperatures for migration, considered to be "At Risk", are an indication that the riparian canopy is insufficient to provide the necessary habitat for this life history.

To summarize, the paucity of LWD necessary for adequate cover, lack of suitable riparian areas to product shade, and the elevated stream temperatures may be factors that limit successful juvenile salmonid migration in the Upper Green and Sunday Creek WAUs.

KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- The Watershed Analysis indicates the riparian habitat is insufficient in the near term to meet the needs of habitat forming processes throughout the study area.
- LWD, low gravel sediment levels, canopy cover, the poor riparian habitat zone and pool quantity and quality are all considered limiting factors to natural salmonid production in the study area.

DATA GAPS

- Comprehensive barrier surveys need to be completed in this subbasin.

LIST OF TABLES

Table Upper Green-1. Matrix of Possible Channel Classifications Used to Group Segments for the Purpose of Establishing Geomorphic Units.

Table Upper Green-2. Definitions of Units and Terms Used in this Report.

Table Upper Green-3. Habitat Units.

Table Upper Green-4. Size criteria Used to Classify Substrate in the Habitat Surveys in the Upper Green River and Sunday Creek WAUs.

Table Upper Green-5. Average Observed Redd Area and Recommended Area per Pair Including Defended Area.

Table Upper Green-6. Examined Key Habitat Parameters for Fall Chinook Reaches in the Green River and Sunday Creek WAUs.

Table Upper Green-7. Examined Key Habitat Parameters for Spring Chinook Reaches in the Green River and Sunday Creek WAUs.

Table Upper Green-8. Examined Key Habitat Parameters for Coho Reaches in the Green River and Sunday Creek WAUs.

Table Upper Green-9. Examined Key Habitat Parameters for Steelhead Reaches in the Green River and Sunday Creek WAUs.

3.11 LESTER WATERSHED ADMINISTRATIVE UNIT

Introduction 2
  Field Measurements and Observations 2
  Information Sources 4
Lester WAU 4
  Salmonid Distribution 5
  Fish Habitat Conditions 6
  Fall Chinook 8
  Spring Chinook 10
  Coho 13
  Steelhead 17
Summary 21
Key findings 22
Data Gaps 22
Identified Limiting Factors to Natural Salmonid Production 22

3.11 LESTER WATERSHED ADMINISTRATIVE UNIT

INTRODUCTION

The Lester WAU consists of an area that is 32,776 acres in size that is drained by the Green River downstream of the confluence with Sunday Creek to the point of its confluence with Smay Creek. Approximately 39 percent of the land in the WAU is administered by the U.S. Forest Service, 39 percent by Plum Creek Timber Company, 16 percent by the City of Tacoma, 5 percent by the Weyerhauser Company and 1 percent by Burlington Northern.

For purposes of the Watershed Assessment (WSA), the Lester WAU was divided into twelve subbasin. The mainstem of the Green River and its smaller tributaries were divided into two subbasins and the ten major tributary subbasins were also delineated. The major tributary basins were: Morgan Creek, Wolf Creek, Champion Creek, Rock Creek, Lester Creek, Sawmill Creek, Friday Creek, Bald Creek, McCain Creek and Green Canyon Creek. These subbasins will be referred to throughout this chapter.

FIELD MEASUREMENTS AND OBSERVATIONS

In the Lester WAUs, stream surveys are conducted and completed during moderate to low flow conditions during 1994 and 1995. The sampled parameters were quantitatively assessed using methodologies for field habitat collection outlined in the State's Ambient Monitoring Manual (Schuett-Hames et al. 1994), the U.S. Forest Service Stream Handbook, and the Watershed Analysis Manual Version 3.0. Sediment samples were collected in riffle crests in accordance to the method of Schuett-Hames et al. (1994) using a McNeil core sampler, and analyzed by the gravimetric method. Temperature recordings were obtained by maximum thermometers, and thermographs recording at 1 hour intervals from July through September, also in accordance to the temperature monitoring methods of Schuett-Hames et al. (1994). Scour information was obtained using scour chains placed in suitable spawning area. Substrate data were categorized into six size classifications (based on the U.S. Forest Service Stream Handbook, 1991), and frequency of occurrence calculated. All visual observations of juvenile and adult fish were also recorded during the surveys to verify DNR Water Type maps.

Any presence of salmonids was determined by surveys that were conducted utilizing methods outlined in the Version 2.0 of the Standard Methodology for Conduction Watershed Analysis (WFPB 1993). Other physical information collected in the surveys included habitat data, potential salmonid passage barriers, and evidence of recent disturbance (<20 years). Streams classified as Type 4 and 5 by the DNR water type maps were selected with priority given to streams on the basis of physical features that indicated a strong likelihood of salmonid presence (e.g. drainage area >50 acres, gradients <20%, low basin elevation, or any combination of these), although several streams beyond these parameters may also be surveyed at the discretion of the survey team. The basin areas selected were prompted by Watershed Analysis in other similar stream basins. Surveys are concentrated on visiting as many streams as possible over the three month survey period of each year. A total of 38 segments were surveyed.

Landslide hazard assessments drew heavily from empirical data obtained by aerial photo analysis. The photo record spanned 34 years from 1958 to 1992 inclusive.

SURVEYS

Surveys are conducted during sampling seasons that are typically during July to October. Survey seasons were limited to this particular window of opportunity to allow for a better chance to observe salmonids due to local salmonid life history cycles. The elevation of stream reaches has a bearing on the ability to observe salmonids. In the Lester WAU, the elevation is relatively high (1400-5400 feet) and resident salmonids or juvenile anadromous salmonids can be lodged deeply within gravels and organic debris. Typically, during colder air and water temperatures food sources are not present for feeding, thus making any salmonid detection more difficult. Also, high flows often occurring outside the survey window likely contribute to difficult detection of salmonids because they are either displaced downstream, under cover in inaccessible interstitial space, or are difficult to see because of water turbidity.

The physical stream characteristics were determined from topographic maps and aerial photographs from 1958 through 1992 inclusive. Where possible, these characteristics are verified in the field utilizing the methods from the TFW Ambient Monitoring protocols (NWIFC, 1994) for determining channel bankfull widths and wetted widths for calculating gradient. Channel length and bankfull width are measured by a hip-chain and tape measure, respectively. Length and width are typically measured to the nearest 1/10th meter. Stream gradient is measured by a hand-held clinometer at 25 meter stations and averaged, and pool depth is measured with a stadia rod from the deepest part of the pool to the water surface. Gradient is measured to the nearest 1 percent and pool depth to the nearest 1/10th meter. Flood plain connectivity is determined by measuring the lineal meters of road adjacent to one or both sides of a stream segment, and dividing by the length of the stream segment to generate a percent reduction in connectivity. Width-to-depth ratio is calculated by dividing the bankfull width by the channel depth. Road density is obtained by measuring road lengths per stream sub-basin using a desktop GIS software product.

METHODS OF ANALYSIS

Both the NFMS “Matrix of Pathways and Indicators” and the Washington State Watershed Analysis “Indices of Resource Conditions” compare observed stream habitat conditions to a standard numerical or narrative descriptions. Both systems group the observed habitat quality or quantity into three broad categories. The WFPB uses “poor”, “fair”, and “good” while the NMFS uses “Not Properly Functioning”, “At Risk”, and “Properly Functioning”. As both systems use three tiers of habitat condition, one can compare the narrative rating of equivalent or roughly equivalent habitat parameters. For the purposes of this report, “poor” was considered equivalent to “not Properly Functioning” and “good” comparable to “Properly Functioning”. As several of the Washington State “Indices of Resource Conditions” metrics are similar to those of the NMFS “Matrix of Pathways and Indicators”, both were listed for the purpose of comparing methods.

Several habitat parameters of the NMFS Matrix of Pathways do not contain threshold criteria in which to determine a habitat condition. For example, “Holding Pools” by the WFPB definition, synonymous with “Pool Quality” by the NMFS matrix, define respective ratings of “Good” and “Properly Functioning” as having “sufficient” pools >1m deep. Terms such as “sufficient”, “few”, and “most” do not have threshold criteria in which to base a determination of whether or not it serves as functional habitat. For this reason, criteria were developed for the parameters that lack thresholds based on best professional judgement based on knowledge of life history requirements of salmonids utilizing these WAUs. Data, as available, were also used to support these determinations. The following criteria were developed for these habitat parameters:

RIPARIAN CONDITIONS

Riparian habitat conditions were used to assess potential sources of riparian wood recruitment, which is used in conjunction with the NMFS parameter of “LWD Quantity” and are described previously in this chapter.

The frequency of deep (>1m) holding pools, flood plain connectivity, off-channel habitats, condition of spawning gravels habitat criteria were all discussed previoulsy in this chapter.

After assessing the quality of salmon habitat for four previously mentioned salmon species, the results are compared to the critical input variables for each life history stage to determine the habitat factors that potentially limit natural salmon production in the Sunday Creek and Upper Green River WAUs.

INFORMATION SOURCES

Information is collected from various sources: USFS stream surveys; Tacoma Public Utilities (TPU) stream flow data, water quality, and anecdotal information; the United States Geological Survey (USGS), the Washington Department of Natural Resources (DNR), the US Army Corps of Engineers (Corps), Washington Department of Fish and Wildlife (WDFW), aerial photos , and the U.S. Fish and Wildlife Service (USFW&S). Field surveys conducted by the fish, channel, and riparian module teams provide the required information not previously collected or available. Fish distribution data for salmonid species was provided by the WDFW Washington Rivers Information System (WARIS), WDFW Priority Habitat and Species list, Washington State Salmon and Steelhead Stock Index (SASSI) (WDFW and WWTIT 1994), and was supplemented by field observations by fisheries biologists.

LESTER WAU

The Lester WAU is situated on the west side of the central Cascade Mountains divide, approximately 16 miles (26 km) south of Snoqualmie Pass along Interstate 90 and entirely within King County, Washington. The Green River is the largest water body within the Lester WAUs.

The base elevation of the Lester WAU is approximately 1,400 feet (425 meters) at the confluence with the Green River. The basins rise to the top of the Cascade divide with an average basin elevation of 5,400 ft (1,646m). Approximately 8 miles (13 kilometers (km)) downstream of the lower WAU boundary, the Green River discharges into Howard Hanson Reservoir, a flood control reservoir operated by the Army Corps of Engineers. Downstream of Howard Hanson Dam (HHD) (at RM 64.5) the Green River flows past the Tacoma Headworks Dam (at RM 61) and enters the Green River Gorge and flows west and eventually flows through the City of Auburn where it turns north and flows through the lower Green River valley and into Elliott Bay near West Seattle. The details of habitat downstream of HHD are contained elsewhere in this report.

SALMONID DISTRIBUTION

The known freshwater distribution of anadromous salmonids is depicted in the report Appendix. There is no historical information concerning salmonid species distribution or abundance in the Lester WAU. However, there is substantial anecdotal information that implies anadromous fish migrated upstream of the Tacoma Headworks Project prior to its completion in 1911. Anadromous fish access into the Lester WAU seems likely, since there are no natural or anthropogenic passage barriers located on the mainstem Green River downstream of the WAU. Historically, adult salmonids were documented at the Tacoma Headworks Diversion Dam (Grette and Salo, 1986), and adults have been documented upstream of the diversion dam site (Riseland, 1913).

Currently, the salmonid species inhabiting the Lester WAU include hatchery releases of fed fry of summer/fall chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), a combination of hatchery and natural production of resident and anadromous (steelhead) rainbow trout (*O. mykiss*), and natural populations of cutthroat trout (*O. clarki*), and mountain whitefish (*Prosopium williamsonni*). Currently, only anadromous steelhead adults are passed upstream of the Tacoma Headworks Project and HHD. Spawning steelhead adults have been observed in the Green River as far upstream as RM 83.5 but they have not been observed in the Lester WAU. The release locations of juvenile steelhead, chinook and coho salmon into the Lester WAU are depicted in Appendix B. Mountain whitefish, cutthroat and resident rainbow trout are known to inhabit the primary tributaries. As of the date of this report there are no reported observations of bull trout (*Salvalinus confluentus*) within the Lester WAU.

There are known resident trout populations in the Lester WAU that include rainbow and cutthroat. These species have a wide distribution, but since no formal inventory has been done, an exact distribution and abundance estimate cannot be determined. Adfluvial trout populations have been observed throughout the lower portions of the Green River in the Lester WAU. Resident trout are found in most of the major Lester WAU tributaries and extend into tributaries classified as "Type 3" waters. Type 4 waters are also likely to contain resident trout populations where the stream gradient is less than 14 percent. Resident trout were found during electrofishing surveys in several Type 4 streams during WSA sampling (Plum Creek 1996). No resident trout were found in streams with gradients in excess of 14 percent (Plum Creek 1996).

The mainstem Green River and all the primary tributary channels support resident rainbow and/or cutthroat trout. While not demonstrated, it is likely that hybridization between the two species has occurred (T. Cropp, WDFW, pers. comm.). Trout in reaches of isolated high-gradient streams are often segregated from other strains by passage barriers, although dispersal by downstream migration frequently occurs. The mainstem Green River, supports a population of cutthroat trout that attain lengths of 20 inches (T. Cropp, pers. comm.). These large and mature fish may represent a stock of adfluvial cutthroat that have matured in the reservoir and ascend the streams to spawn. Spawning activity of the adfluvial strains of trout are believed to occur primarily in the mainstem Green River and in the lower reaches of the accessible tributaries (Wunderlich and Toal, 1992). The stream rearing habitat requirements for resident trout are similar to those of steelhead. As with all species of salmonids using the WAU, relatively shallow, channel margin and pool habitat is important during the earliest stages of life soon after incubation.

FISH HABITAT CONDITIONS

In the Lester WAU Watershed Analyses (WSA), a total of forty-six (46) segments were sampled and surveyed. Anecdotal evidence was noted between sample reaches to obtain inferences on channel character and habitat condition and whether or not the segment was representative of the surveyed. In those 46 segments, a total of 24,739 feet of channel were quantitatively surveyed. The length of sample reaches varied, but a minimum of 328 feet (100 meters) was surveyed. Field evaluations were completed during May thru August 1994.

The Lester WSA did not classify segments by salmon species as was done in the Green River and Sunday Creek WSA. Rather, metrics were repotred by stream segment as shown in Table Lester-1.

Table Lester 1: Pool Habitat in the Lester WAU (Source: Toth 1996)

Segment	Pools (% of channel area)	Pool Frequency*	Mean residual pool depth
2	22	1.2	17.6
5	10	1.3	12.9
B1	14	4.5	9.7
B5	26	2.8	7.4
C1	14	4.5	11.2
C2	18	1.3	13.1
C3	22	1.2	12.0
C9	10	2.1	11.5
D1	25	7.3	14.5
D1a	44	3.6	13.2
D6	37	1.5	10.3
E1	11	2.3	8.5
E14	29	1.1	8.0
E18	33	2.2	12.1
E3	44	0.9	12.6
H1	30	0.8	13.2
H2	17	1.9	0.5
E1H38	47	0.5	10.5
H6	29	1.0	12.3
H6A	42	0.8	23.0
I18	0		
I19	35	2.7	8.0
I2	8	2.1	0.9
I20	34	2.1	9.9
I3	30	0.7	11.6
I6	26	1.8	1.2
I7	24	1.4	1.0
I8	6	5.8	0.9
K2	29	4.7	1.2
K2A	25	1.4	14.1

The field metrics identified in the NMFS "Matrix of Pathways" were quantified for habitats utilized by each species.

The following discussion relates the existing quality of habitat in the upper Green and Sunday Creek WAUs for each species to their respective life history requirements. This is accomplished by evaluating the effects associated with each respective critical input variable, which often dictates habitat quality.

FALL CHINOOK

Information was reviewed from six survey reaches that covered 1,118 meters of stream channel. These six survey reaches represent 18.3 percent of the presumed fall chinook habitat available in the Green River and Sunday Creek WAUs as identified by the Army Corps of Engineers (1998). Overall, the quality of fall chinook habitat is rated as "Not Properly Functioning". The key parameters examined are identified in Table Lester-2.

Table Lester 2: Examined Key Habitat Parameters for Fall Chinook Reaches in the Green River and Sunday Creek WAUs

Parameter	Minimum	Maximum	Mean	SD	N=
Survey Reach Length (m)	100	218	186	43.0	6
BFW (m)	5.3	20.9	11.2	5.3	6
Bankfull Depth (m)	0.40	0.6	0.5	0.1	6
Gradient (%)	1.5	3.0	2.4	0.7	6
Elevation (m)	558	607	588	18.7	6
Pools/mile	22.2	80.5	41.7	27.1	6
Holding Pools/mile	0	48.3	18.7	16.7	6
Percent of all pools that are holding/pools per mile	0%	67	43.6	26.5	6
Off-channel Habitat	0	45	11.7	16.9	6
Riparian Species 1=conifer, 2=deciduous	1	2	1.7	0.52	6
Riparian Age 1=old, 2=mature, 3=young	2	3	2.7	0.52	6
Riparian density: 1=dense, 2=sparse	1	2	1.2	0.41	6
Percent wood cover in pools	0-5%	5-10%	4.5%	2.7%	5
Width/depth ratio	13.3	37.3	21.2	8.4	6
Occurrence of sand, silt, clay (%)	0	25	4.17	10.21	6
Occurrence of gravel, cobble (%)	10	90	57.38	32.37	6
Occurrence of boulder/bedrock (%)	0	90	38.00	36.46	6
Anadromous Spawning Area (%)	0	2	0.67	0.82	6
Percent fines	16	16	16	0	1
Temperature (F)	62.24	62.24	62.24	0	1
Canopy Closure (%)	0%	78%	16.2%	30.9%	6
Min. shade requirement (%)*	47%	51%	48.5%	1.5%	6
NMFS wood pieces/mile	0	29.5	4.92	12.06	6

* Source: WFPB 1998.

RIPARIAN HABITAT

Watershed Analysis found that the bulk of the riparian habitats in the Green River and Sunday Creek WAUs are generally dense, but young deciduous trees. This condition is insufficient as a new LWD supply to the stream channel and hence maintain or improve the associated habitat forming processes. This situation will likely not ameliorate until the riparian stands reach a size and age that would allow for sufficient size and number to restore instream LWD loadings to a more natural level. The riparian condition is currently considered to be "Not Properly Functioning" for fall chinook in four of the six reaches surveyed and "At Risk" in the remaining two. These ratings are due to: (1) the deciduous component of trees that dominate the assessed riparian reaches for fall chinook; and (2) the young age of the trees present in the riparian area.

The young tree age and large deciduous component are likely directly responsible for the scarcity of NMFS criteria LWD present in the stream channel. The quantity of LWD within the fall chinook reaches is insufficient to maintain many of the necessary habitat elements and habitat forming elements. Though pieces of wood are numerous, they are typically small. Only four pieces of wood were found that meet NMFS size criteria within the survey fall chinook reaches. This represents only 7.1 percent of the 56 pieces needed to be considered "Properly Functioning". None of the reaches surveyed met NMFS criteria for wood quantity, nor are the channel adjacent stands considered to be adequate to maintain LWD recruitment processes in the near term. Thus, for fall chinook this yields a "Not Properly Functioning" assessment.

SUBSTRATE

WSA indicates that spawning gravels are in short supply throughout the reaches examined. Surveys indicate that a mean of 0.76 percent of the total surveyed stream channel was observed to contain potential suitable spawning substrate. Three of the six reaches surveyed were dominated by boulder/bedrock and the remaining three reaches were dominated by gravel/cobble with very little gravel distributed in areas that were deemed useful for fall chinook spawning. Overall, the paucity of suitable spawning gravels in the reaches surveyed are a limiting factor for fall chinook production and were rated as "Not Properly Functioning".

Mass wasting and hillslope erosion was determined not to be a significant contributor to the overall levels of fine sediment produced in the Green River and Sunday Creek WAUs. Secondary sediment erosion from mass wasting scarps generally was below the 50 percent of the natural background sediment input cutoff point for a moderate hazard rating designation. There was one exception, the Pioneer Creek subbasin, where the estimated sediment yield is 57 percent of the background.

POOLS

Of the 24 reaches surveyed, the number of pools varied considerably. Using pool frequencies as calculated from the pool frequency regression curve, 16 of the 24 surveyed reaches do not meet NMFS criteria for "Properly Functioning" for pool frequency. When taken in the aggregate, the streams had roughly the required number of pools required to meet MNFS criteria as "Properly Functioning". Cumulatively, the surveyed reaches had 26 pools in fall chinook reaches where 28.4 were to be expected. Two of the six reaches surveyed had more pools than required and overly compensated for the other four reaches that had far fewer than the required number of pools. However, despite the number of pools present, all of the reaches, including those that met NMFS pool criteria to be considered "Properly Functioning" are assigned an "At Risk" factor because of the inadequacy of the riparian zone to recruit LWD into the stream channel to form pools.

Approximately 44 percent of the pools surveyed met minimum depth requirements (>1 meter). The ability of the pools to provide cover and holding areas is further reduced by the pool inwater and overwater cover, again because of the lack of LWD. Pool quality was deemed insufficient to provide suitable habitat for fall chinook as was assigned an "At Risk" rating.

CHANNEL CONDITIONS

Reach specific and cumulative observations suggest that the stream channel has become shallow and wide. This may also be an influencing factor in decreased pool quality and adversely impacts the ability of the available habitat to successfully hold adult and rear juvenile salmonids. The mean width:depth ratio was 21.22. This indicates increased proportion of riffles and glides that leads to reduced high flow refugia and available over-winter rearing habitats, an increased water surface area exposed to solar radiation that in turn could lead to increased stream water temperatures. Additionally, the high width to depth ratio may influence fall chinook spawning through decreases in wetted stream areas with acceptable depths for spawning fall chinook. A designation of “Not Properly Functioning” was assigned to stream channel conditions because of the high width:depth ratio.

OFF-CHANNEL HABITAT

Six reaches were surveyed for the quantity of off-channel habitat. Only one of these six reaches was ranked as “Properly Functioning” with 45 percent of the off-channel habitat in this reach skewed the mean value to 11.7 percent. However, this single reach is not representative of the other five stream reaches as noted by the high variability, which is illustrated by a standard deviation of 16.9 percent. Three of the six reaches are rated as “Not Properly Functioning” while the others are rated as “At Risk”. Overall, off-channel habitats are rated as “Not Properly Functioning” again due to the scarceness of LWD and the off-channel habitat forming processes associated with LWD.

WATER QUALITY

Water temperature was measured in one stream as 62.2 F, which would give a rating of “Not Properly Functioning”. A probable cause of elevated stream temperatures is that the mean canopy closure is only 24.0 percent while 41.3 percent canopy coverage is required to meet shade standards (WFPB 1998) to avoid solar radiation and induced water temperature increases.

SPRING CHINOOK

Information was reviewed from twelve (12) survey reaches that covered 1,742 meters of stream channel. These twelve survey reaches represent 16.6 percent of the presumed spring chinook habitat available in the Green River and Sunday Creek WAUs as identified by the Army Corps of Engineers (1998). The key parameters examined are identified in Table Lester-3.

Table Lester-3: Examined Key Habitat Parameters for Spring Chinook Reaches in the Green River and Sunday Creek WAUs

Parameter	Minimum	Maximum	Mean	SD	N=
Survey Reach Length (m)	24	218	145	64.1	12
BFW (m)	4	21	10	438	12
Bankfull Depth (m)	0.4	1.5	1	0.4	12
Gradient (%)	1.5	5	2.5	0.4	12
Elevation (m)	558	723	635.4	58.4	12
Pools/mile	0	134.1	44.1	38.5	12
Holding Pools/mile	0	48.3	9.3	14.9	12
Percent of all pools that are holding/pools per mile	0%	67	26	30	10
Off-channel Habitat	0	45	1.3	16.2	9
Riparian Species 1=conifer, 2=deciduous	1	3	1.8	0.4	6
Riparian Age 1=old, 2=mature, 3=young	2	3	2.8	0.4	6
Riparian density: 1=dense, 2=sparse	1	2	1.2	0.4	6
Percent wood cover in pools	0.5%	5-10%	0-5%	---	9
Width/depth ratio	7.3	37.3	16.1	7.9	6
Occurrence of sand, silt, clay (%)	0	25	3.0	7.6	6
Occurrence of gravel, cobble (%)	10	100	69.1	30.4	6
Occurrence of boulder/bedrock (%)	0	90	27.80	32.4	6
Anadromous Spawning Area (%)	0	6	1.3	1.8	10
Percent fines	16	16	16	0	1
Temperature (F)	58.1	67.2	60.2	2.9	5
Canopy Closure (%)	0%	93%	20.7%	31.9%	12
Min. shade requirement (%)*	37%	51%	44.3%	5.1%	12
NMFS wood pieces/mile	0	257.6	27.3	73.8	12

* Source: WFPB 1998.

RIPARIAN HABITAT

Watershed Analysis found that the bulk of the riparian habitats that could be utilized by spring chinook in the Green River and Sunday Creek WAUs are generally dense, but young deciduous trees. This condition is insufficient as a new LWD supply to the stream channel and hence maintain or improve the associated habitat forming processes. This situation will likely not ameliorate until the riparian stands reach a size and age that would allow for sufficient size and number to restore instream LWD loadings to a more natural level. The riparian condition is currently considered to be "Not Properly Functioning" for spring chinook in ten of the twelve reaches surveyed and "At Risk" in the remaining two. These ratings are due to: (1) the deciduous component of trees that dominate the assessed riparian reaches for fall chinook; and (2) the young age of the trees present in the riparian area.

The young tree age and large deciduous component are likely directly responsible for the scarcity of NMFS criteria LWD present in the stream channel. The quantity of LWD within the spring chinook reaches is insufficient to maintain many of the necessary habitat elements and habitat forming elements. None of the reaches surveyed met NMFS criteria for wood quantity, nor are the channel adjacent stands considered to be adequate to maintain LWD recruitment processes in the near term. Thus, for spring chinook this yields a "Not Properly Functioning" assessment.

SUBSTRATE

WSA indicates that spawning gravels are in short supply throughout the reaches examined. Surveys indicate that a mean of 1.3 percent of the total surveyed stream channel was observed to contain potential suitable spawning substrate. Individual reaches also reflected poor spawning gravel quality. Eleven of the twelve reaches were rated as "Not Properly Functioning" due to inadequate area of spawnable gravels. Boulder/bedrock was the dominant feature in four reaches while gravel/cobble dominated the remaining eight. The gravel/cobble reaches contained very little gravel distributed in areas that could be utilized by spawning spring chinook. Only one reach (mainstem Green River at RM 86.4) that contained 6 percent spawning gravel was considered "At Risk", the remaining reaches were all considered to be "Not Properly Functioning". Overall, the paucity of suitable spawning gravels in the reaches surveyed are a limiting factor for spring chinook production and were rated as "Not Properly Functioning".

Mass wasting and hillslope erosion was determined not to be a significant contributor to the overall levels of fine sediment produced in the Green River and Sunday Creek WAUs. Secondary sediment erosion from mass wasting scarps generally was below the 50 percent of the natural background sediment input cutoff point for a moderate hazard rating designation. There was one exception, the Pioneer Creek subbasin, where the estimated sediment yield is 57 percent of the background.

POOLS

Overall, the spring chinook reaches surveyed had 85 percent of the required number of pools to meet NMFS as "Properly Functioning". However, the poor quality of the pools and the inadequate stream adjacent riparian reserves strongly suggest that a lower habitat quality rating be assigned than consideration of pool frequency alone would suggest.

Of the twelve reaches surveyed, the number of pools varied considerably. Using pool frequencies as calculated from the pool frequency regression curve, nine of the twelve surveyed reaches do not meet NMFS criteria for "Properly Functioning" for pool frequency. When taken in the aggregate, the streams had roughly the required number of pools required to meet MNFS criteria as "Properly Functioning". Cumulatively, the surveyed reaches had 41 pools in spring chinook reaches where 48 were to be expected. Individually, nine of the twelve reaches had a pool deficit and are rated as "Not Properly Functioning". However, on a system wide basis, these numerical deficiencies were almost compensated by reaches containing more pools than required. However, despite the number of pools present, all of the reaches, including those that met NMFS pool criteria to be considered "Properly Functioning" are assigned an "At Risk" factor because of the inadequacy of the riparian zone to recruit LWD into the stream channel to form pools. Without LWD inputs into the stream channel it should be expected that there will be a net decrease over time of pool quality and pool numbers.

Approximately 26 percent of the pools surveyed met minimum depth requirements (>1 meter). The ability of the pools to provide cover and holding areas is further reduced by the pool inwater and overwater cover, again because of the lack of LWD. Cover in all pools was considered poor, with a mean coverage in the 0-5 percent range. Pool quality was deemed insufficient to provide suitable habitat for spring chinook as was assigned an "At Risk" rating.

CHANNEL CONDITIONS

Reach specific and cumulative observations suggest that the stream channel has become shallow and wide. This may also be an influencing factor in decreased pool quality and adversely impacts the ability of the available habitat to successfully hold adult and rear juvenile salmonids. The mean width:depth ratio was 16.1. This indicates increased proportion of riffles and glides that leads to reduced high flow refugia and available over-winter rearing habitats, an increased water surface area exposed to solar radiation that in turn could lead to increased stream water temperatures. Additionally, the high width to depth ratio may influence fall chinook spawning through decreases in wetted stream areas with acceptable depths for spawning fall chinook.

Individually, two of the twelve surveyed reaches met the NMFS criteria to be defined as “Properly Functioning” while two were “At Risk” and the remaining eight were “Not Properly Functioning”.

A designation of “Not Properly Functioning” was assigned to stream channel conditions because of the high width:depth ratio.

OFF-CHANNEL HABITAT

Nine reaches were surveyed for the quantity of off-channel habitat. Only two of these nine reaches was ranked as “Properly Functioning”, three were ranked as “At Risk” and five at “Not Properly Functioning”. Two reaches with exceptionally large percentages of off-channel rearing (45% and 32%) skewed the mean value to 11.3 percent. However, this single reach is not representative of the other five stream reaches as noted by the high variability, which is illustrated by a standard deviation of 16.2 percent. Overall, off-channel habitats are rated as “Not Properly Functioning” again due to the scarceness of LWD and the off-channel habitat forming processes associated with LWD.

WATER QUALITY

Water temperature was measured in one stream as 60.2 F, which would give a rating of “Not Properly Functioning”. A probable cause of elevated stream temperatures is that the mean canopy closure is only 20.7 percent while 44 percent canopy coverage is required to meet shade standards (WFPB 1998) to avoid solar radiation and induced water temperature increases.

COHO

Information was reviewed from 24 reaches that were surveyed that were considered to support coho salmon. This represented an area covering 3,652 meters of stream channel and further represents approximately 17.8 percent of the presumed coho habitat in the Green River and Sunday Creek WAUs. Key parameters of the coho habitat survey are presented in Table Lester-4 below.

Lester-4: Examined Key Habitat Parameters for Coho Reaches in the Green River and Sunday Creek WAUs

Parameter	Minimum	Maximum	Mean	SD	N=
Survey Reach Length (m)	24	300	152.0	77.0	24
BFW (m)	4	38	13.2	8.3	24
Bankfull Depth (m)	0.37	2.5	0.98	0.66	24
Gradient (%)	1.0	6.0	2.6	1.4	24
Elevation (m)	529	723	612	59.7	24
Pools/mile	0	134.1	37.0	32.6	24
Holding Pools/mile	0	48.3	9.2	11.8	24
Percent of all pools that are holding/pools per mile	0	100	35	35	21
Off-channel Habitat	0	49	10.2	16.6	16
Riparian Species 1=conifer, 2=deciduous	1	2	1.8	0.4	23
Riparian Age 1=old, 2=mature, 3=young	2	3	2.9	0.3	23
Riparian density: 1=dense, 2=sparse	1	2	1.2	0.4	23
Percent wood cover in pools	0-5%	5-10%	0-5%	2.7	16
Width/depth ratio	6.0	37.3	15.2	6.6	24
Occurrence of sand, silt, clay (%)	0	25	3.2	7.6	24
Occurrence of gravel, cobble (%)	0	100	66.7	32.4	24
Occurrence of boulder/bedrock (%)	0	100	24.3	32.0	24
Anadromous Spawning Area (%)	0	13.0	2.1	3.1	21
Percent fines	6	16	11.0	7.1	2
Temperature (F)	57.2	62.24	59.1	2.0	5
Canopy Closure (%)	0	93	21.3	25.7	24
Min. shade requirement (%)*	20%	54	42.8	9.6	24
NMFS wood pieces/mile	0	257	30.2	65.7	24

* Source: WFPB 1998.

RIPARIAN HABITAT

Watershed Analysis found that the bulk of the riparian habitats that could be utilized by coho in the Green River and Sunday Creek WAUs are generally dense, but consist of young deciduous trees. This condition is insufficient as a new LWD supply to the stream channel and hence maintain or improve the associated habitat forming processes. This situation will likely not ameliorate until the riparian stands reach a size and age that would allow for sufficient size and number to restore instream LWD loadings to a more natural level. The riparian condition is currently considered to be "Not Properly Functioning" for coho in 20 of the 23 reaches surveyed and "At Risk" in the remaining three. These ratings are due to: (1) the deciduous component of trees that dominate the assessed riparian reaches for fall chinook; and (2) the young age of the trees present in the riparian area. The condition of the riparian habitat is currently not sufficient in the near term to provide suitable amounts and quality of LWD to the stream channel to maintain associated habitat and other ecological forming processes. Without large coniferous trees for recruitment and retention, the existing level of coho production should be expected to decline.

The mean pieces of WSA size wood (>10 centimeters diameter, >2 meters length) per channel width was 3.0. A rating of good is assigned to stream channels with at least 2.0 pieces per channel width (WFPB 1997). However, this good rating is strongly influenced by one reach in the mainstem Green River (RM85.8) where a segment long log jam contained an average of 34 pieces per channel width. In the absence of this log jam, the number of wood pieces per channel width over the surveyed habitat would be 1.7, yielding a rating of "Fair" under WSA standards. This patchy distribution of wood in the stream channel is indicated by the standard deviation of 7.1 pieces per channel width.

WSA key pieces are also below the desired target numbers, averaging only 0.02 pieces per channel width. This represents less than 10 percent of the target goal of 0.3 pieces per channel width.

When NMFS criteria are applied, only 56 pieces of wood were identified within the reaches surveyed for coho salmon. This represents only 31 percent of the target level of 181 pieces required to be considered "Properly Functioning" by NMFS. This yields an overall habitat rating as "Not Properly Functioning".

SUBSTRATE

WSA indicates that spawning gravels are in short supply and inadequate for adult coho salmon spawning throughout the reaches examined. Surveys indicate that a mean of 2.1 percent of the total surveyed stream channel was observed to contain potential suitable spawning substrate where the desired threshold is 10 percent. Individual reaches also reflected poor spawning gravel quality. Twenty of the twenty-one reaches were rated as "Not Properly Functioning" due to inadequate area of spawnable gravels. The gravel/cobble reaches category dominated (67%) the reaches but contained very little gravel distributed in areas that could be utilized by spawning coho. Only one reach (mainstem Green River at RM 86.4) that contained 13 percent spawning gravel was considered "Properly Functioning", while the remaining reaches were all considered to be "Not Properly Functioning". Overall, the paucity of suitable spawning gravels in the reaches surveyed are a limiting factor for coho production and were rated as "Not Properly Functioning".

Mass wasting and hillslope erosion was determined not to be a significant contributor to the overall levels of fine sediment produced in the Green River and Sunday Creek WAUs. Secondary sediment erosion from mass wasting scarps generally was below the 50 percent of the natural background sediment input cutoff point for a moderate hazard rating designation. There was one exception, the Pioneer Creek subbasin, where the estimated sediment yield is 57 percent of the background.

Fine sediment sampled in two reaches was measured at 6 percent and 16 percent. A mean of fines of 11.0 percent is considered to be "Properly Functioning" (NMFS).

POOLS

Overall, the coho reaches surveyed had 81 percent of the required number of pools to meet NMFS as "Properly Functioning". However, the poor quality of these pools and the inadequate stream adjacent riparian reserves strongly suggest that a lower habitat quality rating be assigned than consideration of pool frequency alone would suggest.

Of the 24 reaches surveyed, the number of pools varied considerably. Using pool frequencies as calculated from the pool frequency regression curve, 16 of the 24 surveyed reaches do not meet NMFS criteria for "Properly Functioning" for pool frequency. When taken in the aggregate, the streams had roughly the required number of pools required to meet MNFS criteria as "Properly Functioning". Cumulatively, the surveyed reaches had 75 pools in coho reaches where 91 were to be expected. However, on a system wide basis, these numerical deficiencies were almost compensated by reaches containing more pools than required. However, despite the number of pools present, all of the reaches, including those that met NMFS pool criteria to be considered "Properly Functioning" are assigned an "At Risk" factor because of the inadequacy of the riparian zone to recruit LWD into the stream channel to form pools. Without LWD inputs into the stream channel it should be expected that there will be a net decrease over time of pool quality and pool numbers.

Approximately 35 percent of the pools surveyed met minimum depth requirements (>1 meter). The ability of the pools to provide cover and holding areas is further reduced by the pool in-water and overwater cover, again because of the lack of LWD. Cover in all pools was considered poor, with a mean coverage in the 0-5 percent range. Pool quality was deemed insufficient to provide suitable habitat for spring chinook as was assigned an "At Risk" rating.

CHANNEL CONDITIONS

Reach specific and cumulative observations suggest that the stream channel has become shallow and wide. This may also be an influencing factor in decreased pool quality and adversely impacts the ability of the available habitat to successfully hold adult and rear juvenile salmonids. The mean width:depth ratio was 15.2. This indicates increased proportion of riffles and glides that leads to reduced high flow refugia and available over-winter rearing habitats, an increased water surface area exposed to solar radiation that in turn could lead to increased stream water temperatures. Additionally, the high width to depth ratio may influence coho spawning through decreases in wetted stream areas with acceptable depths for spawning coho.

Individually, three of the 24 surveyed reaches met the NMFS criteria to be defined as "Properly Functioning" while five were "At Risk" and the remaining 18 were "Not Properly Functioning".

A designation of "Not Properly Functioning" was assigned to stream channel conditions because of the high width:depth ratio.

OFF-CHANNEL HABITAT

The quantity of off-channel habitat is cumulatively 10.2 percent of the total wetted area and is considered to be "Properly Functioning". However, on an individual basis, only four of the 16 reaches surveyed achieve a rating of "Properly Functioning".

WATER QUALITY

Water temperature as measured in five streams averaged 59.1 F giving an overall rating of "At Risk". A probable cause of elevated stream temperatures is that the mean canopy closure is only

20.5 percent while 42 percent canopy coverage is required to meet shade standards (WFPB 1998) to avoid solar radiation and induced water temperature increases.

STEELHEAD

Information was reviewed from 29 surveyed reaches that were considered to support steelhead. This represented an area covering 4,352 meters of stream channel and further represents approximately 20.3 percent of the presumed steelhead habitat in the Green River and Sunday Creek WAUs. Key parameters of the steelhead habitat survey are presented in Table Lester-5 below.

Table Lester-5: Examined Key Habitat Parameters for Steelhead Reaches in the Green River and Sunday Creek WAUs

Parameter	Minimum	Maximum	Mean	SD	N=
Survey Reach Length (m)	24	300	150.1	77.7	29
BFW (m)	4.0	38.0	13.0	7.8	29
Bankfull Depth (m)	0.4	2.5	1.1	0.7	29
Gradient (%)	1.0	11.0	3.0	2.0	29
Elevation (m)	529	838	635.7	78.1	29
Pools/mile	0	134.1	40	34.5	29
Holding Pools/mile	0	48.3	8.6	11.7	29
Percent of all pools that are holding/pools per mile	0	100	29	34	26
Off-channel Habitat	0	49	9.5	15.8	18
Riparian Species 1=conifer, 2=deciduous	1	2	1.8	0.4	28
Riparian Age 1=old, 2=mature, 3=young	2	3	2.9	0.3	28
Riparian density: 1=dense, 2=sparse	2	1	1.1	0.4	28
Percent wood cover in pools	0-5%	5-10%	0-5%	N/A	18
Width/depth ratio	6.0	37.3	14.3	6.4	29
Occurrence of sand, silt, clay (%)	0	25	2.9	7.1	28
Occurrence of gravel, cobble (%)	0	100	61.5	33.5	28
Occurrence of boulder/bedrock (%)	0	100	34.2	36.3	28
Anadromous Spawning Area (%)	0	13	2	2.9	25
Percent fines	6	16	11.0	7.1	2
Temperature (F)	57.2	62.2	59.6	2.2	5
Canopy Closure (%)	0	93.0	24.0	25.3	29
Min. shade requirement (%)*	20	54	41.3	9.4	29
NMFS wood pieces/mile	0	257.6	26.6	60.3	29

* Source: WFPB 1998.

RIPARIAN HABITAT

Watershed Analysis found that the bulk of the riparian habitats that could be utilized by steelhead in the Green River and Sunday Creek WAUs are generally dense, but consist of young deciduous trees. This condition is insufficient as a new LWD supply to the stream channel and hence maintain or improve the associated habitat forming processes. This situation will likely not ameliorate until the riparian stands reach a size and age that would allow for sufficient size and number to restore instream LWD loadings to a more natural level. The riparian condition is currently considered to be “Not Properly Functioning” for steelhead in 25 of the 28 reaches surveyed and “At Risk” in the remaining three. These ratings are due to: (1) the deciduous component of trees that dominate the assessed riparian reaches for steelhead; and (2) the young age of the trees present in the riparian area. The condition of the riparian habitat is currently not sufficient in the near term to provide suitable amounts and quality of LWD to the stream channel to maintain associated habitat and other ecological forming processes. Without large coniferous trees for recruitment and retention, the existing level of steelhead production should be expected to decline.

The mean pieces of WSA size wood (>10 centimeters diameter, >2 meters length) per channel width was 2.8. A rating of good is assigned to stream channels with at least 2.0 pieces per channel width (WFPB 1997). However, this good rating is strongly influenced by one reach in the mainstem Green River (RM85.8) where a segment long log jam contained an average of 34 pieces per channel width. In the absence of this log jam, the number of wood pieces per channel width over the surveyed habitat would be 1.7, yielding a rating of "Fair" under WSA standards. This patchy distribution of wood in the stream channel is indicated by the standard deviation of 7.0 pieces per channel width.

WSA key pieces are also below the desired target numbers, averaging only 0.03 pieces per channel width. This represents less than 20 percent of the target goal of 0.15 pieces per channel width.

When NMFS criteria are applied, only 59 pieces of wood were identified within the reaches surveyed for steelhead. This represents only 27.3 percent of the target level of 216 pieces required to be considered "Properly Functioning" by NMFS. Individually, two of the 29 reaches met NMFS wood requirement criteria. However, due to the young deciduous conditions adjacent to the stream channel, potential wood recruitment sources will be unable to maintain or improve the necessary wood loadings. This yields an overall habitat rating as "Not Properly Functioning".

SUBSTRATE

WSA indicates that spawning gravels are in short supply and inadequate for adult steelhead spawning throughout the reaches examined. Surveys indicate that a mean of 2.0 percent of the total surveyed stream channel was observed to contain potential suitable spawning substrate where the desired threshold is 10 percent. Individual reaches also reflected poor spawning gravel quality. Twenty-four of the twenty-five reaches were rated as "Not Properly Functioning" due to inadequate area of spawnable gravels. The gravel/cobble reaches category dominated 17 of the 28 reaches (60.7%) but contained very little gravel distributed in areas that could be utilized by spawning steelhead. Only one reach (mainstem Green River at RM 86.4) that contained 13 percent spawning gravel was considered "Properly Functioning", while the remaining reaches were all considered to be "Not Properly Functioning". Overall, the paucity of suitable spawning gravels in the reaches surveyed are a limiting factor for steelhead production and were rated as "Not Properly Functioning".

Mass wasting and hillslope erosion was determined not to be a significant contributor to the overall levels of fine sediment produced in the Green River and Sunday Creek WAUs. Secondary sediment erosion from mass wasting scarps generally was below the 50 percent of the natural background sediment input cutoff point for a moderate hazard rating designation. There was one exception, the Pioneer Creek subbasin, where the estimated sediment yield is 57 percent of the background.

POOLS

Overall, the steelhead reaches surveyed had more than the required number of pools to meet NMFS as "Properly Functioning". However, the poor quality of these pools and the inadequate stream adjacent riparian reserves strongly suggest that a lower habitat quality rating be assigned than consideration of pool frequency alone would suggest.

Of the 29 reaches surveyed, the number of pools varied considerably. Cumulatively, using pool frequencies as calculated from the pool frequency regression curve, the reaches contained 98 pools and exceeded the NMFS requirement of 90 pools. However, on an individual basis, 18 of the 29 surveyed reaches do not meet NMFS criteria for "Properly Functioning" for pool frequency and in fact would be considered as "Not Properly Functioning". However, on a system wide basis, these numerical deficiencies were almost compensated by reaches containing more pools than required. Despite the number of pools present, all of the reaches, including those that met NMFS pool criteria to be considered "Properly Functioning" are assigned an "At Risk" factor because of the inadequacy of the riparian zone to recruit LWD into the stream channel to form pools. Without LWD inputs into the stream channel it should be expected that there will be a net decrease over time of pool quality and pool numbers.

Approximately 29 percent of the pools surveyed met minimum depth requirements (>1 meter). The ability of the pools to provide cover and holding areas is further reduced by the pool in-water and overwater cover, again because of the lack of LWD. Cover in all pools was considered poor, with a mean coverage in the 0-5 percent range. Pool quality was deemed insufficient to provide suitable habitat for spring chinook as was assigned an "At Risk" rating.

CHANNEL CONDITIONS

Of the 29 surveyed reaches for steelhead, only five met the NMFS criteria for "Properly Functioning", eight can be described as "At Risk" and the remaining sixteen as "Not Properly Functioning". Reach specific and cumulative observations suggest that the stream channel has become shallow and wide. This may also be an influencing factor in decreased pool quality and adversely impacts the ability of the available habitat to successfully hold adult and rear juvenile salmonids. The mean width:depth ratio was 14.3, where a target of less than 10 is required to meet favorable channel conditions. This indicates increased proportion of riffles and glides that leads to reduced high flow refugia and available over-winter rearing habitats, an increased water surface area exposed to solar radiation that in turn could lead to increased stream water temperatures. Additionally, the high width to depth ratio may influence steelhead spawning through decreases in wetted stream areas with acceptable depths for spawning steelhead.

A designation of "Not Properly Functioning" was assigned to stream channel conditions because of the high width:depth ratio.

OFF-CHANNEL HABITAT

The quantity of off-channel habitat is cumulatively 9.5 percent of the total wetted area and is considered to be "At Risk". However, on an individual basis, only four of the 18 reaches surveyed achieve a rating of "Properly Functioning". Therefore, natural production of steelhead is considered to be limited by the lack of off-channel rearing opportunities in the Green River and Sunday Creek WAUs.

WATER QUALITY

Water temperature as measured in five streams averaged 59.6 F giving an overall rating of "At Risk" for juvenile steelhead rearing and adult summer steelhead that might be migrating, holding or spawning in these reaches. A probable cause of elevated stream temperatures is that the mean canopy closure is only 24.0 percent while 41.3 percent canopy coverage is required to meet shade standards (WFPB 1998) to avoid solar radiation and induced water temperature increases.

SUBSTRATE

The quality of spawning habitat is dictated by the abundance of spawnable gravels, adjacent cover, and riparian shade. This is in turn affected by coarse and fine sediment, large wood, riparian vegetation, and flow. Spawning gravel is considered to be "Not Properly Functioning" for any of the salmon species present. A number of factors could be contributing to this alone or collectively. This could be a result influenced by the lack of LWD that serves to trap gravels, which is at levels considered to be "Not Properly Functioning" (NMFS) or poor (WFPB). Also, the cover component in pools, important for salmonid spawning may also be limiting due to is present rating of "poor" (WFPB). Furthermore, the stream temperatures for spawning is considered to be "At Risk" (NMFS) for all species except fall chinook, in which this condition is considered to be "Not Properly Functioning" (NMFS). The influence of the riparian area is likely to contribute to the lack of large wood, elevated stream temperatures, and lack of cover. The riparian condition is considered to be "Not Properly Functioning" (NMFS) for all the aforementioned salmon species.

Fine sediment is considered to be "At Risk" for coho and steelhead. Fine sediment can inhibit redd excavation and incubation, as noted previously. Fine sediment does not currently limit fall and spring chinook spawning, in which this metric is considered to be Properly Functioning (NMFS).

Mass wasting and hillslope erosion was determined not to be a significant contributor to the overall levels of fine sediment produced in the Green River and Sunday Creek WAUs. Secondary sediment erosion from mass wasting scarps generally was below the 50 percent of the natural background sediment input cutoff point for a moderate hazard rating designation. There was one exception, the Pioneer Creek subbasin, where the estimated sediment yield is 57 percent of the background.

SUMMARY

In summary, anadromous salmonid spawning habitat is limited by 1) the lack of suitable spawning gravels, 2) elevated stream temperatures, and 3) the lack of cover in pools. These components are influenced by the loss of LWD, which is lacking in the system, a poor riparian condition, which is also “Not Properly Functioning” condition, and fine sediment for coho and steelhead spawning habitat, which is considered to be “At Risk”.

Summer rearing habitat requires the use of large deep pools and off-channel areas that provide adequate water flow, ample cover, cool water temperatures, optimal feeding opportunities, inter- and intra- species interaction, and opportunities, depending on needs, to hold in slow or fast moving water. The factors that influence summer-rearing habitat are channel form, gradient, small and large in-stream wood, canopy closure, and food input. Riparian vegetation and in-stream wood provide cover and channel complexity during this phase. Pool area and pool quality, large wood, cover in pools, and riparian vegetation are considered to be “Not Properly Functioning” for coho, steelhead, fall and spring chinook, and thus are likely to limit summer rearing opportunities and success.

Winter rearing areas provide stable and non-turbid stream flow during storm events. This habitat also must provide adequate flow, cover, and temperatures that facilitate metabolic conservation. The majority of the confined streams in the Upper Green River and Sunday Creek WAUs have only limited ability to form off-channel and wetland areas due to their confinement by road and railway grades. In the absence of side channels, salmonids typically are forced to over-winter in the substrate and under the protection of wood. Off-channel habitat is in short supply for coho and steelhead, and considered to be “At Risk”; however, this habitat is considered to be “Properly Functioning” for fall and spring chinook (NMFS).

The “At Risk” condition of winter-rearing habitat for coho and steelhead in the upper Green and Sunday Creek WAUs is likely caused by several factors. When LWD abundance is compared to NMFS criteria the large logs that contribute to off-channel habitat formation are in short supply and thus are likely to limit winter rearing. The riparian canopy, which helps to maintain ambient stream temperatures at night, is also in a “Not Properly Functioning” condition (NMFS). Interstitial substrate is adversely affected by overloading the stream with fine sediment, as indicated by the “At Risk” rating for fine sediment (NMFS), which reduces the available winter rearing habitat.

To summarize, winter-rearing habitat is limited for coho and steelhead in the Green and Sunday Creek WAUs. The lack of LWD is likely a limiting factor that contributes to the formation of these habitats. The quality of winter-rearing habitat is also reduced by the inadequate riparian condition, the elevated levels of fine sediment, and the lack of cover in pools.

Cover is an important component for juvenile salmonid migration, as is a normal temperature regime. LWD, which helps to provide cover to protect salmonids from predators, direct sunlight, and high water temperatures, is in short supply for all the species considered in this analysis (NMFS). The riparian vegetation, which provides shade and cover to the stream, is also considered to be lacking (NMFS). The elevated stream temperatures for migration, considered to be “At Risk”, are an indication that the riparian canopy is insufficient to provide the necessary habitat for this life history.

To summarize, the paucity of LWD necessary for adequate cover, lack of suitable riparian areas to product shade, and the elevated stream temperatures may be factors that limit successful juvenile salmonid migration in the Upper Green and Sunday Creek WAUs.

KEY FINDINGS

- The Watershed Analysis indicates the riparian habitat is insufficient in the near term to meet the needs of habitat forming processes throughout the study area.

DATA GAPS

- Comprehensive barrier surveys need to be completed in this subbasin.

IDENTIFIED LIMITING FACTORS TO NATURAL SALMONID PRODUCTION

- LWD, low gravel sediment levels, canopy cover, the poor riparian habitat zone and pool quantity and quality are all considered limiting factors to natural salmonid production in the study area.

LIST OF TABLES

Table Lester-1: Pool Habitat in the Lester WAU

Table Lester-2: Examined Key Habitat Parameters for Fall Chinook Reaches in the Green River and Sunday Creek WAUs

Table Lester-3: Examined Key Habitat Parameters for Spring Chinook Reaches in the Green River and Sunday Creek WAUs

Table Lester-4: Examined Key Habitat Parameters for Coho Reaches in the Green River and Sunday Creek WAUs

3.12 INDEPENDENT NEARSHORE TRIBUTARIES IN WRIA 9)

Introduction 2
Joe's Creek 2
Physical Description 2
Factors of Decline 3
Lakota Creek (09.0386) 6
Physical Description 6
Factors of Decline 7
Cold Creek (09.0381) 10
Physical Description 10
Factors of Decline 10
Buenna Creek (09.0384) 13
Physical Description 13
Factors of Decline 13
Salmon Creek (09.0362) 15
Physical Description 15
Factors of Decline 16
Miller Creek (09.0371) 19
Physical Description 19
Factors of Decline 19
Des Moines Creek (09.0377) 22
Physical Description 22
Factors of Decline 22
Fauntleroy Creek (09.0361) 27
Physical Description 27
Factors of Decline 27
Key Findings and Habitat-Limiting Factors 30
Data Gaps 30

3.12 INDEPENDENT NEARSHORE TRIBUTARIES IN WRIA 9

INTRODUCTION

The nearshore tributaries of WRIA 9 include 15 independent streams that directly enter Puget Sound (Longfellow Creek was historically an independent tributary but it currently flows into the West Waterway and is discussed as a Green River tributary). The numbering system used in this report is that described by Williams (1975). The first two digits designate the WRIA number, and the remaining numbers identify individual streams. Bordered by Fauntleroy Creek to the north and Joe's Creek to the south, these streams include:

- Joe's Creek (09.0369) (also called Younglove Creek in some of the literature);
- Lakota Creek;
- Cold Creek
- Buenna Creek;
- Salmon Creek;
- Miller Creek;
- Des Moines Creek;
- Fauntleroy Creek;
- McSorley Creek;
- Woodmont Creek;
- Redondo Creek;

Three unnamed creeks north of Three Tree Point (09.0367, 09.0353 and 09.070); and an unnamed creek (09.0380) immediately south of Des Moines Creek. All are typical of Puget Sound lowland drainages that receive their flow from springs, seeps, lake outlets, rainfall and groundwater runoff. All of these creeks have experienced the types of habitat degradation associated with industrial development and/or urbanization.

This chapter presents information on Joe's, Lakota, Cold, Buenna, Salmon, Miller, De Moines, and Fauntleroy creeks. Miller and Des Moines creeks are the largest and generally have the largest amount of information. Little or no information is available for McSorley, Woodmont, and Redondo creeks, or for the unnamed creeks.

JOE'S CREEK

PHYSICAL DESCRIPTION

STREAM COURSE AND MORPHOLOGY

The East Fork of Joe's Creek (09.0369) is a seasonal stream fed by surface runoff. A stormwater detention pond on the south side of 340th Street empties into the streambed via a culvert with the stream first surfacing immediately south of SW 338th Street. This fork then flows through

Olympic View Park and the Twin Lakes Golf Course to meet the West Fork Joe's Creek at the stormwater detention pond on SW 320th Street.

The West Fork Joe's Creek is a fed by groundwater and surface runoff that begins at a stormwater detention pond at the Wedgewood Apartments and Golf Course. The streambed then follows Hoyt Road North to the constructed Lakes Lorene and Jeane (also known as Twin Lakes). It flows out of the northeast portion of Lake Jeane, through the Twin Lakes Golf Course and into another holding pond and joins the East Fork.

The mainstem of Joe's Creek currently has its origins from this stormwater detention pond on the south side of SW 340th Street. Joe's Creek then drops into a high-gradient stream channel that falls through a wooded ravine, eventually flattening immediately prior to entering Puget Sound on the east side of Dumas Bay.

SALMONID USE

Historically, salmon were observed as far upstream as the first culvert beneath 320th Street. However, salmon have not been observed this far upstream for at least several decades (Kimpo and Maher 1997).

The known freshwater distribution of anadromous salmonids is depicted in the Fish Distribution Maps located in the Appendix. In Joe's Creek there is the occasional report by local residents of adult salmon observed. However, the species of salmon is unknown.

Several age classes of juvenile cutthroat trout have been observed by Puyallup tribal fisheries biologists (Ladley pers. comm.).

Both creeks flow directly into Dumas Bay and provide an important freshwater input into this area of Puget Sound. Dumas Bay has been characterized as a 253-acre intertidal sandflat habitat integral to the nearshore ecosystem in this part of Puget Sound. No data are available detailing juvenile or salmonid usage of this area. However, coastal cutthroat trout have been observed being caught (J. Kerwin pers. obser.), and juvenile chinook salmon, chum salmon, and steelhead have been captured in beach seine sets (NRC 1995) in Dumas Bay.

FACTORS OF DECLINE

RIPARIAN CONDITION

The riparian habitat in this stream does not meet any criteria of properly functioning. The lack of adequate riparian habitat is a limiting factor to natural salmonid production.

The riparian communities along Joe's Creek are composed primarily of young trees, shrubs, non-native species, and ornamental plantings. It is almost completely lacking medium or large trees that would provide the shade necessary to support salmonid habitat. Aerial photos show that most of Joe's Creek streambed channel is visible from above, indicating that existing shade levels are less than 25 percent. The target shade percentage deemed necessary to maintain temperatures below 16°C at this elevation ranges from 80 to 90 percent.

Only the riparian habitat in the reach from RM 0.1 to 1.0 is considered suitable to provide good shade at the present time. This area support stands of maturing deciduous and coniferous trees are considered to be in fair condition. Left undisturbed and allowed to mature, they will provide shade for this area of the channel.

Land use activities upstream of this point will preclude achieving good shade conditions along the remainder of Joe's Creek. In particular, the residential development, recreational land use in areas adjacent to the channel upstream of RM 1.0 will continue to prohibit development of mature riparian vegetation capable of providing shade.

Large Woody Debris

No specific information on historic amounts of LWD was located during this investigation. However, based on channel type, it is assumed that laterally-stable, moderate- to high-gradient reaches of the lower mile supported dense stands of conifers (including Douglas-fir, western red cedar, and western hemlock). The trees were removed through logging and development.

There is no systematic survey of present amounts of LWD in Joe's Creek. The lack of tall, mature trees effectively limits the supply of organic matter and terrestrial insects delivered to Joe's Creek. Limited amounts of LWD is present in the lower river mile (Kerwin 2000). If left undisturbed, the trees in these areas will mature and begin to provide functional LWD.

The potential for LWD recruitment throughout the remainder of Joe's Creek subbasin is poor, as land use activities effectively preclude the development of mature riparian stands.

HYDROLOGY

Impervious surfaces associated with single and multi-family residences, commercial activities and roads are the primary contributors to high flows and large sediment loads in the tributaries and mainstem of Joe's Creek. Peak flows are believed to be exceed 150 percent over historical flows (Federal Way 1990). Because the land is largely built out, current peak flows in these creeks are likely to approximate future flows.

SEDIMENT CONDITION

Impervious surfaces associated with single- and multi-family residences are the primary contributors to high flows and large sediment loads in this creek. Because riparian communities along Joe's Creek are composed primarily of young trees, shrubs, non-native species, and ornamental plantings, none of the stream system is considered to have good bank stability.

The presence of dense stands of young coniferous or deciduous trees or shrubs is sufficient to provide good sediment filtration where the riparian zone is at least 150 feet wide. Only in the reach between RM 0.1 to 1.0 are there sufficient amounts and distance to provide good sediment filtration. However, this is the high-gradient ravine where the creek transitions from the headwater to beach. Upstream of this point, roads, development or other contributing activities adjacent to the stream effectively eliminate the ability of riparian area to filter fine sediment.

The substrate within this creek consists of pebbles and cobble-sized particles with localized sand depositions. Gravel deposits are very local and spawning opportunities are typically few. These features are typical of flow alterations caused by unretained or underretained stormwater.

With the conversion of the historic forested uplands into low- and high-density residences, water fluctuation and sedimentation have increased (King County 1991). Siltation (caused by construction activities, increases of impervious surfaces and associated peak flood flows) have resulted in local flooding concerns that further degrade salmonid habitats.

WATER QUALITY

Joe's Creek appears on the 1998 Department of Ecology 303(d) water quality violations list for exceeding fecal coliforms.

High percentages of impervious surfaces in this area indicate that contaminates in surface water runoff likely adversely impact salmonids.

LAND USE

Upstream, the creek is bordered by residential areas with little or no riparian habitat present. Olympic View Park is located immediately downstream of the confluence of the East and West forks. This public park has a thin wooded strip along the creek of approximately 100 feet on either side of the creek. Numerous bicycle and pedestrian trails transect this buffer and impair its ability to function as a riparian habitat. Joe's Creek passes also through low- and high-density residential housing areas, Twin Lakes and Northshore golf courses, and Twin Lakes (two constructed ornamental lakes not identified in Wolcott (1965)).

The lower river mile of this creek passes through a ravine bordered by a 200- to 500-foot-wide corridor of second-growth (up to 28 inches in diameter) red cedar, western hemlock and Douglas fir. This vegetation stabilizes the slopes that are up to 150 feet high with slopes in the range of 60 to 90 percent.

NON-NATIVE SPECIES

Animals

No exotic aquatic animal species were identified in the stream reaches that anadromous salmonids inhabit during the course of this investigation. Warmwater fish species have been reported in some of the lakes in the upper reaches of Joe's Creek and its tributaries.

Plants

Reed canarygrass (*Phalaris arundinacea*) is abundant throughout this subbasin. Other exotic plant communities in the riparian zone consist of Himalayan blackberries and willow species (*Salix spp.*), and numerous ornamental plantings associated with the golf courses and residential communities.

HYDROMODIFICATION

No information was located that showed current vs. historic stream channel. However, given the extensive residential development and the presence of several thousand feet of culvert in this subbasin, there is little doubt that the streambed has been relocated in some reaches.

The mainstem creek and its tributaries are crossed by nine roads in a relatively short distance. In addition, the mainstem Joe’s Creek travels for approximately 600 feet through a culvert as it exits a water detention pond at the Twin Lakes Golf Course. The West Fork of Joe’s Creek travels through five culverts for a combined distance of approximately 1,350 feet. The East Fork of Joe’s Creek travels through two culverts for a combined approximate distance of 1,150 feet.

Off Channal Habitat

No information was located that described site specific-historical riparian conditions along mainstem Joe’s Creek. In general, it is likely that vegetation in the Joe’s Creek subbasin was similar to that elsewhere in the Puget Sound region. There are numerous small ponds and lakes in the upland areas that form the headwaters of the tributaries. Soils maps suggest there were also numerous wetlands in the upper Soos Creek basin. A mixture of emergent wetlands probably characterized these areas or wet meadows intermixed with forested wetlands and uplands supporting Douglas-fir on the dryer sites. The canyon reach (RM 0.1 to RM 1.0) most likely supported a dense stand of conifers. Riparian vegetation communities would have been similar to that described for the middle Green River in the vicinity of Soos Creek.

LAKOTA CREEK (09.0386)

PHYSICAL DESCRIPTION

SUBBASIN

The Lakota Creek subbasin is located entirely within the City of Federal way. It drains an area of approximately 1,387 acres, and has 24 acres of lakes and 8 acres of wetlands. The subbasin contains a complex system of tributaries; many of which are roadside-associated drainage ditches, stormwater detention ponds, and ornamental ponds.

STREAM COURSE AND MORPHOLOGY

In the eastern portion of the subbasin, all of the tributaries (Northeast Limb, Southeast Limb, Southeast Wetland and Mirror Lake Overflow) drain into Fisher’s Pond. Water from this pond flows into the South Central Limb, the Southwest Wetlands and the North Central Limb, which converge at the North Fork Wetlands. These collectively form the North Fork (NF) Lakota Creek which meets the South Fork (SF) Lakota Creek along SW Dash Point Road. Lakota Creek then continues along the road in a northwesterly direction, passing through the Lakehaven Sewage and Wastewater Treatment Plant before entering Puget Sound at Dumas Bay. Lakota Creek provides an important freshwater input into this area of Puget Sound.

SALMONID USE

The known freshwater distribution of anadromous salmonids is depicted in Appendix B, Figures 1-6. Adult salmon have been reported spawning in the lower reaches of Lakota Creek (WDFW Spawning Ground Survey Database, Anthony and Catton 1996). Chum salmon were observed spawning in the 1990s, and an occasional coho adult has been reported. Surveys in 1987 found juvenile coho salmon (as well as cutthroat and steelhead trout and sculpins) (Shapiro and Assoc. 1987). Several age classes of juvenile cutthroat trout have been observed by Puyallup tribal fisheries biologists (Ladley 1999).

No data are available detailing juvenile or salmonid usage of Dumas Bay. However, coastal cut-throat trout have been observed being caught in Dumas Bay (Kerwin 2000). Juvenile chinook salmon, chum salmon, and steelhead were captured in beach seine sets in Dumas Bay during surveys conducted in 1995 (NRC 1995).

FACTORS OF DECLINE

FISH PASSAGE

A culvert under Highway 509 (Dash Point Road) creates a blockage to anadromous fish and eliminates further upstream access.

RIPARIAN CONDITION

Very little intact riparian habitat exits in the subbasin. Narrow strips of young coniferous forests are present in the vicinity of Decatur High School but generally the creek flows through residential areas and alongside roads. The riparian habitat along the lower reaches of Lakota Creek currently consists of small deciduous trees with an understory of shrubs.

Similar to bank stability, shade is considered to be in good condition only where there are dense stands of medium or large sized coniferous or deciduous trees. The Lakota Creek streambed channel was generally visible on aerial photos, indicating that existing shade levels are less than 25 percent. The target shade percentage deemed necessary to maintain temperatures below 16^{o}C at this elevation ranges from 80 to 90 percent. Land use activities throughout the Lakota Creek subbasin will preclude achieving good shade. In particular, the residential development, recreational land use in areas adjacent to the channel upstream of RM 1.0 will continue to prohibit development of mature riparian vegetation capable of providing shade.

Large Woody Debris

No specific information on historic amounts of LWD was located during the investigation for this report. Based on channel type, it is assumed that laterally-stable moderate to high gradient contained reaches of the lower mile supported dense stands of conifer including Douglas-fir, western red cedar, and western hemlock. The riparian communities associated with unconfined low- and moderate-gradient reaches upstream of the crest of the bluff were probably similar stands to those in the ravine.

There were not any systematic surveys of current LWD amounts located as a part of this investigation for this subbasin.

Without exception, the potential for LWD recruitment throughout the Lakota Creek subbasin is poor. Within the lower 1.0 creek mile corridor, if left undisturbed and as the riparian stand matures, it will begin to provide functional LWD within the next 50 – 100 years. LWD recruitment along the remainder of Lakota Creek is expected to remain low, as land use activities effectively preclude the development of mature riparian stands.

HYDROLOGY

Impervious surfaces associated with single and multi-family residences, commercial activities and roads are the primary contributors to high flows and large sediment loads in the tributaries and mainstem of Lakota Creek. Peak flows are believed to exceed 150 percent over historical flows (Federal Way 1990). Because the land is largely built out, current peak flows in these creeks are likely to approximate future flows.

SEDIMENT CONDITION

Because riparian communities along Lakota Creek are composed primarily of young trees, shrubs, non-native species and ornamental plantings none of the stream system is considered to have good bank stability. The substrate within this creek consists of pebbles and cobble-sized particles with localized sand depositions. Gravel deposits are very local and spawning opportunities are typically few. These features are typical of flow alterations caused by unretained or underretained stormwater. A sediment detention basin constructed at the entrance to the Dakota Treatment Plant is emptied after major storms. This is indicative of continuing erosion problems upstream of this point

With the conversion of the historic forested uplands into low and high density residences increases in water fluctuation and sedimentation have occurred (King County 1991). Siltation, caused by construction activities, increases in impervious surfaces and associated peak flood flows have all contributed to local flooding concerns.

WATER QUALITY

Water quality is adversely impacted by the high percentage of impervious surfaces within the subbasin and the presence of domestic trash throughout the stream channel is both an aesthetic and water quality problem.

Lakota Creek appears on the 1998 Department of Ecology 303(d) water quality violations list for exceeding fecal coliforms.

LAND USE

No information was located that described site specific historical riparian conditions along mainstem Lakota Creek or its tributaries. A land survey conducted by the U.S. Geological Survey in

1897 (USGS 1900) indicates that in the lower reaches of Lakota Creek, the timber had been harvested and restocked while the upper reaches appeared to be unharvested and were described as “Merchantable forests.” One area around Mirror Lake appeared as a “Burnt area restocking.”

With the exception of the lower river mile, all of the area adjoining Lakota Creek is heavily developed.

NON-NATIVE SPECIES

Reed canarygrass, Himalayan blackberries and numerous ornamental plantings are abundant throughout this subbasin. Other exotic plant communities in the riparian zone consist of Himalayan blackberries and willow species, and numerous ornamental plantings associated with the golf courses and residential communities.

HYDROMODIFICATION

Floodplain Modifications

No information was located during the course of this investigation that compared or showed current vs. historic stream channel.

The lower reach of the stream was relocated as a part of an upgrade to the Lakehaven Sewage and Wastewater Treatment Plant in 1987. A bypass (overflow) culvert takes the portion of the creek that is not accommodated in the stream channel and empties directly into Dumas Bay southwest of the Lakota Creek mouth. Given the extensive residential development, the parallel stream course to roads, the presence of numerous road crossings, and stormwater detention ponds there is little doubt that the streambed has been relocated in numerous reaches.

Off Channel Conditions

In general, it is likely that vegetation in the Lakota Creek subbasin was similar to that elsewhere in the Puget Sound region. There are numerous small ponds and lakes in the upland areas that form the headwaters of the tributaries. Soils maps suggest there were also numerous wetlands in the Lakota Creek subbasin. A mixture of emergent wetlands or wet meadows intermixed with forested wetlands and uplands supporting Douglas-fir and western Hemlock on the dryer sites probably characterized these areas. Riparian vegetation communities would have been similar to that described elsewhere in this report for the middle Green River in the vicinity of Soos Creek.

The majority of these wetlands have been drained and filled for development purposes

COLD CREEK (09.0381)

PHYSICAL DESCRIPTION

STREAM COURSE AND MORPHOLOGY

Located entirely within the city limits of Federal Way, Cold Creek is listed by Williams (1975) as an unnamed tributary and designated as stream number 09.0382. The creek originates from Easter Lake and together with its tributary (09.0382) is approximately 1.55 miles in length (8,200 feet) (Cutler pers. comm). After leaving Easter Lake the creek follows S 308th Street prior to entering a culvert and resurfaces in the vicinity of South 306th Street where it almost immediately enters a steep ravine prior to entering Puget Sound.

SALMONID USE

The known freshwater distribution of anadromous salmonids is depicted in Appendix B, Figures 1-6. Local residents occasionally report adult coho and chum salmon in the lower reaches, but dates and numbers could not be confirmed during this investigation. The Washington Department of Fish and Wildlife Spawning Ground Survey Database does not have any information showing observations of any salmonid species in this creek.

FACTORS OF DECLINE

RIPARIAN CONDITION

The upstream portion of Cold Creek passes through low- and high-density residential housing areas, and commercial developments and the riparian corridor is severely degraded.

The lower reach of Cold Creek and into the lower end of the ravine has a riparian habitat consisting of second-growth deciduous and coniferous trees, shrubs, non-native species, and ornamental plantings. Areas such as the reach between RM 0.1 and RM 0.33 that support stands of mixed deciduous and coniferous trees are considered to be in fair condition, and will attain good condition if left undisturbed and allowed to mature.

Similar to bank stability, shade is considered to be in good condition only where there are dense stands of medium or large sized coniferous or deciduous trees. The Cold Creek streambed channel was generally visible on aerial photos, indicating that existing shade levels are less than 25 percent. The target shade percentage deemed necessary to maintain temperatures below 16^{o}C at this elevation ranges from 80 to 90 percent. Only the riparian habitat in the reach from RM 0.05 to 0.33 is considered suitable to provide good shade at the present time. Land use activities upstream of this point will preclude achieving good shade conditions along the remainder of Cold Creek. In particular, the residential development, recreational land use in areas adjacent to the channel upstream of RM 0.33 will continue to prohibit development of mature riparian vegetation capable of providing shade.

Large Woody Debris

No data was located that indicated the current condition of riparian zones with respect to organic matter and terrestrial insect recruitment. The lack of tall, mature trees is thought to effectively limit the supply of organic matter and terrestrial insects delivered to Cold Creek.

No specific information on historic amounts of LWD was located during the investigation for this report. Based on channel type, it is assumed that laterally-stable moderate to high gradient contained reaches of the lower mile supported dense stands of conifer including Douglas-fir, western red cedar, and western hemlock. The riparian communities associated with unconfined low and moderate gradient reaches upstream of the crest of the bluff probably similar stands to those in the ravine. In Cold Creek there have not been any systematic surveys of current LWD amounts that could be located as a part of this investigation for this subbasin.

With the exception of the lower 0.33 mile of Cold Creek, the potential for LWD recruitment throughout the subbasin is poor. Within the lower 0.33 mile corridor, if left undisturbed and as the riparian stand matures, it will begin to provide functional LWD. LWD recruitment along the remainder of Cold Creek is expected to remain low, as land use activities effectively preclude the development of mature riparian stands.

HYDROLOGY

Impervious surfaces associated with commercial development, single- and multi-family residences are the primary contributors to high flows and large sediment loads in the tributaries and mainstem of Joe’s Creek. Localized flooding around Easter Lake has been the cause of some concern by local residents. Because the land is largely built out, current peak flows in this creek are likely to approximate future flows.

SEDIMENT CONDITION

The presence of dense stands of young coniferous or deciduous trees or shrubs are sufficient to provide good sediment filtration where the riparian zone is at least 150 feet wide. Only in the reach between RM 0.1 to 0.5 (the canyon reach) are there sufficient amounts and distance to provide good sediment filtration. However, this is the high gradient reach of the stream that is in the ravine where the creek transitions from the headwater to beach. Upstream of this point, roads, development or other contributing activities adjacent to the stream effectively eliminate the ability of riparian area to filter fine sediment.

The substrate within this creek consists of pebble and cobble sized particles with localized sand depositions. Gravel deposits are very local and spawning opportunities are typically few. These features are typical of flow alterations caused by unretained or underretained stormwater.

WATER QUALITY

Water quality is adversely impacted by the high percentage of impervious surfaces within the subbasin.

The presence of domestic trash throughout the stream channel is both an aesthetic and water quality problem.

Cold Creek appears on the 1998 Department of Ecology 303(d) water quality violations list for exceeding fecal coliforms.

HYDROMODIFICATION

No information was located during the course of this investigation that showed current vs. historic stream channel. However, given the extensive residential and commercial development present there is little doubt that the streambed has been relocated in some reaches.

There are a minimum of nine storm drains that contribute stormwater runoff to Cold Creek. Four of these enter Easter Lake and five directly enter the creek. The Easter Lake drains convey water from a largely commercial area.

NON-NATIVE SPECIES

Animals

No exotic aquatic animal species were identified in the stream reaches that anadromous salmonids inhabit during the course of this investigation.

Plants

Reed canarygrass (*Phalaris arundinacea*) is abundant throughout this subbasin. Other non-native plant communities in the riparian zone consist of Himalayan blackberries and willow species (*Salix spp.*), and numerous ornamental plantings associated with residential communities and commercial developments.

HYDROMODIFICATION

No information was located that described site-specific historical riparian conditions along mainstem Cold Creek. In general, it is likely that vegetation in the Cold Creek subbasin was similar to that elsewhere in the Puget Sound region. A mixture of emergent wetlands probably characterized the upper reaches and wet meadows intermixed with forested wetlands and uplands supporting Douglas-fir on the dryer sites. The canyon reach (RM 0.05 to RM 0.5) most likely supported a dense stand of conifers. Riparian vegetation communities would have been similar to that described for the middle Green River in the vicinity of Soos Creek.

The majority of these wetlands have been drained and filled for development purposes

BUENNA CREEK (09.0384)

PHYSICAL DESCRIPTION

STREAM COURSE MORPHOLOGY

Buenna Creek (and its unnamed, unnumbered tributary stream) is a seasonal intermittent stream system fed by surface runoff that flows directly into Puget Sound just south of Redondo. The mouth of the creek is perched above the normal high water tide line, effectively limiting access by anadromous fish.

SALMONID USE

There is no known utilization of this creek by salmonids. The known freshwater distribution of anadromous salmonids is depicted in Appendix B, Figures 1-6.

FACTORS OF DECLINE

FISH PASSAGE

No impediments to fish passage were identified from existing databases during the course of this investigation.

RIPARIAN CONDITION

No information was located that described site-specific historical riparian conditions along main-stem Buenna Creek. Jones (2000) described riparian land use as a combination of existing residential and early successional forest with a 15-foot buffer from the stream channel at the development of Redondo Bay. Plant communities included an overstory of deciduous trees with an understory of Himalayan blackberry, salmonberry, vine maple and stinging nettle (Jones 2000). In general, it is likely that vegetation in the Buenna Creek subbasin was similar to that elsewhere in the Puget Sound region. Historic riparian vegetation communities would have been similar to that described for the middle Green River in the vicinity of Soos Creek.

No data was located that indicated the current condition of riparian zones with respect to organic matter and terrestrial insect recruitment. The lack of tall, mature trees is thought to effectively limit the supply of organic matter and terrestrial insects delivered to Buenna Creek. The absence of suitable riparian habitat is an indicator that effective sediment filtration can not occur in this creek.

Section 22-1306 of the Federal Way Code requires a 50-foot setback from the ordinary. The City of Federal Way Code, Section 22-1, divides streams into two definitions. Major streams are defined as supporting under normal circumstances resident or migratory fish. Minor streams is defined as any stream that does not mean the definition of a major stream. Buenna Creek has been determined by the City of Federal Way to be a “minor creek”. It was not clear how the development of Redondo Bay was granted a 15-foot stream buffer.

The Buenna Creek streambed channel was generally visible on aerial photos, indicating that existing shade levels are less than 25 percent. Land use activities will preclude achieving good shade conditions along Buenna Creek.

Large Woody Debris

No specific information on historic amounts of LWD was located during the investigation for this report. Based on channel type, it is assumed that laterally-stable moderate- to high-gradient contained reaches of the lower 0.25 mile once supported dense stands of conifer including Douglas-fir, western red cedar, and western hemlock. The riparian communities associated with unconfined low- and moderate-gradient reaches upstream of the crest of the bluff probably similar stands to those in the ravine. In Buenna Creek there were not any systematic surveys of current LWD amounts located as a part of this investigation for this subbasin.

Without exception, the potential for LWD recruitment throughout the Buenna Creek subbasin is poor and is expected to remain poor, as land use activities effectively preclude the development of mature riparian stands.

HYDROLOGY

No information was located that provided an approximation of historic, current or future flows during the course of this investigation. Because the land is largely built out, current peak flows in these creeks are likely to approximate future flows.

SEDIMENT CONDITION

Impervious surfaces associated with single and multi-family residences, commercial development and roads are the primary contributors to high flows and large sediment loads in these creeks.

Because riparian communities along Buenna Creek are composed primarily of young trees, shrubs, non-native species, and ornamental plantings, none of the stream system is considered to have good bank stability.

The substrate within this creek consists of pebble and cobble sized particles with localized sand depositions. Gravel deposits are very local and spawning opportunities are typically few. These features are typical of flow alterations caused by unretained or underretained stormwater.

WATER QUALITY

Water quality is adversely impacted by the high percentage of impervious surfaces within the subbasin. The presence of domestic trash throughout the stream channel is both an aesthetic and water quality problem.

Buenna Creek does not appear on the 1998 Department of Ecology 303(d) water quality violations list for exceeding any water quality parameters.

LAND USE

Jones (2000) described riparian land use as a combination of existing residential and early successional forest.

NON-NATIVE SPECIES

Animals

No exotic aquatic animal species were identified in the stream reaches that anadromous salmonids inhabit during the course of this investigation.

Plants

Reed canarygrass (*Phalaris arundinacea*) is abundant throughout this subbasin. Other non-native plant communities in the riparian zone consist of Himalayan blackberries and willow species (*Salix spp.*), and numerous ornamental plantings associated with the golf courses and residential communities.

HYDROMODIFICATION

No information was located during the course of this investigation that showed current vs. historic stream channel. However, with the extensive residential development and the presence of several culvert sections of stream channel there is little doubt that the streambed has been relocated in some reaches.

SALMON CREEK (09.0362)

PHYSICAL DESCRIPTION

STREAM COURSE AND MORPHOLOGY

Salmon Creek and its tributaries encompass a 2.3-square-mile drainage basin in western King County. The basin's northern boundary is in the vicinity of Southwest Henderson Street inside the city limits of the City of Seattle. The eastern boundary is in the vicinity of Fourth Avenue SW, the western boundary is immediately east of 21st Avenue SW, and the southern boundary borders the Miller Creek subbasin along approximately 126th Street.

Williams (1975) lists the headwaters as Garrett Lake, locally called Hicks Lake (Wolcott 1967), while Heller et al (1987) determined that the headwaters are located in a wetland just north of Southwest 100th Street. Ames (1981) listed four unnamed tributaries, while Heller et al. (1987) found 13 unnamed tributaries. The stream system empties directly into Puget Sound south of Seola Beach.

SALMONID USE

The known freshwater distribution of anadromous salmonids is depicted in Appendix B, Figures 1-6. While the name of the mainstem creek suggests that anadromous salmonids may have been historically present, there have been no recent observations of any species of anadromous salmonids in this system. The only recorded observations are from a spot spawning ground survey conducted on December 27, 1956. One hundred twenty-eight chum salmon adults were observed in unnamed tributary 09.0365, and 95 chum salmon adults were observed in unnamed tributary 09.0366 (WDFW Spawning Ground Survey Database).

FACTORS OF DECLINE

FISH PASSAGE

Access for anadromous salmonids is blocked by a total barrier at approximately RM 0.3.

RIPARIAN CONDITION

Only limited information was located that described site-specific historical riparian conditions along mainstem Salmon Creek or any of its tributaries.

The riparian habitat in the reach where Salmon Creek drops off the bluff through a ravine is the best of any riparian habitats in this subbasin. Consisting of a deciduous-dominated second-growth forest with some conifers and a shrub understory, the riparian zone in this reach is “Fair” according to the criteria contained in the report Appendix.

Similar to bank stability, shade is considered to be in good condition only where there are dense stands of medium or large sized coniferous or deciduous trees. Where the Salmon Creek subbasin streambed channel was on the surface it was generally visible on aerial photos, indicating that existing shade levels are less than 25 percent. Inside the ravine, the stream channel was more difficult to observe. The riparian habitat appears good but the target shade percentage deemed necessary to maintain temperatures below 16^{o}C at this elevation ranges from 80 to 90 percent. Land use activities throughout this subbasin will preclude achieving good shade conditions. In particular, the residential and commercial development in the areas adjacent to the stream channels will continue to prohibit development of mature riparian vegetation capable of providing shade.

Overall, the riparian habitat in this stream does not meet any criteria of properly functioning. The lack of adequate riparian habitat is a limiting factor to natural salmonid production.

Large Woody Debris

No specific information on historic amounts of LWD was located during the investigation for this report. Based on channel type, it is assumed that laterally-stable moderate- to high-gradient contained reaches of the lower mile supported dense stands of conifer including Douglas-fir, western red cedar, and western hemlock. The riparian communities associated with unconfined low- and moderate-gradient reaches upstream of the crest of the bluff probably had similar stands to those in the ravine.

No data was located that indicated the current condition of riparian zones with respect to organic matter and terrestrial insect recruitment. The lack of tall, mature trees is thought to effectively limit the supply of organic matter and terrestrial insects delivered to creeks in this subbasin.

Without exception, the potential for LWD recruitment in the low gradient reaches in this subbasin is poor. The stream reach in the ravine has better potential due to better riparian habitat but land use practices throughout the subbasin generally preclude any LWD recruitment.

HYDROLOGY

Local flooding, undersized water conveyance systems associated with the streams in this subbasin, and impervious surfaces associated with single and multi-family residences are the primary contributors to high flows and large sediment loads throughout this subbasin (Heller 1987). Because of local channelization there is little opportunity to buffer peak flows in the lower reaches. Because the land is largely built out, current peak flows in this creek are likely to approximate future flows.

SEDIMENT CONDITION

Impervious surfaces associated with single- and multi-family residences, commercial development, and the road infrastructure are the primary contributors to high flows and large sediment loads. Stream flows directed over the steep slopes in the western portion of this subbasin have caused excessive downcutting and created several ravines.

No quantitative information on substrate composition was found during the course of this investigation. Heller (1987) noted several instances where sedimentation problems associated with landslides resulted in poor water quality.

Because riparian communities in this subbasin are composed primarily of young trees, shrubs, exotic species (i.e.: reed canary grass along roadside ditches) and ornamental plantings none of the stream system is considered to have good bank stability.

WATER QUALITY

Water quality is adversely impacted by the high percentage of impervious surfaces within the subbasin. The presence of domestic trash throughout the stream channel is both an aesthetic and water quality problem.

This creek does not appear on the 1998 Department of Ecology 303(d) water quality violations list for exceeding fecal coliforms.

LAND USE

The land use within this subbasin is primarily single-family residences, followed by multi-family, commercial development, and schools and parks that have large tracts. It is expected that this land use pattern will continue, although there may be some conversion of single-family residences to multi-family residences.

NON-NATIVE SPECIES

Reed canarygrass (*Phalaris arundinacea*) is found in localized areas along the stream throughout this subbasin. Other exotic plant communities in the riparian zone consist of Himalayan blackberries and willow species (*Salix spp.*), and numerous ornamental plantings associated with the private and public facilities.

HYDROMODIFICATION

In general, it is likely that the historic vegetation communities in the Salmon Creek subbasin was similar to that elsewhere in the Puget Sound region. There are numerous small ponds and lakes in the upland areas that form the headwaters of the tributaries. Soils maps suggest there were also numerous wetlands in the upper Salmon Creek subbasin. A mixture of emergent wetlands probably characterized these areas or wet meadows intermixed with forested wetlands and uplands supporting Douglas-fir on the dryer sites. The canyon reach (RM 0.1 to RM 0.8) most likely supported a dense stand of conifers. Riparian vegetation communities would have been similar to that described for the middle Green River in the vicinity of Soos Creek.

No information was located during the course of this investigation that showed current vs. historic stream channel. However, given the extensive residential development and the presence reaches that are within culverts in this subbasin there is little doubt that the streambed has been relocated in some reaches.

Development throughout the Salmon Creek subbasin has had numerous impacts to channel conditions.

Approximately the first 400 feet of the lower reaches of the mainstem creek have been engineered and are channelized and rock lined in an effort to stabilize the streambanks and channel bottom. At several points, the stream is entirely within long stretches of culverts. Upstream of that point, the next approximate 1,500 feet are unmodified.

Heller (1987) noted at least four points where Salmon Creek or one of its tributaries entered pipes. The unnamed tributary 09.0362 from RM 0.0-0.15 has been straightened and channelized. An impassable barrier occurs in that same stream at RM 0.01.

The placement of the stream inside pipes in the central and northern portions of the basin have left no functioning riparian habitat. A sewer line has been placed in the remaining natural system in the lower 1/3 of the subbasin. Numerous single-family residences have been constructed on potential landslide terrain along the incised ravines of the lower one-third of the subbasin.

Localized flooding as a result of stream channel alterations and undersized water conveyance facilities were found to be problems in the subbasin.

Heller (1987) noted several concerns with erosion and landslides. These included tributaries 09.0362C and 09.0363 that had numerous locations where the channels were downcutting and flow associated landslides were present, and drainage from a roof that had apparently caused a landslide, which in turn endangered a private single-family residence.

Heller (1987) also noted the presence and accumulation of trash in the stream channel and ravines of this subbasin.

MILLER CREEK (09.0371)

PHYSICAL DESCRIPTION

STREAM COURSE AND MORPHOLOGY

The Miller Creek subbasin is located in southwest King County, with the eastern boundary formed by SeaTac Airport, the City of Normandy Park to the south, with the plateau edge above Seahurst and the hill line north of Arbor Lake forming the western and northern boundaries respectively. A complex system of at least 15 locally named and unnamed tributaries form the Miller Creek subbasin. The tributaries of the upper basin have their origins on a rolling till plateau with glacial outwash sediment partially filling broad swales from which small lakes, bogs and depressions serve as the origins for these tributaries. Arbor and Tubs (sometimes referred to as Bug Lake) Lakes form the headwaters of two of the tributary streams. The other tributaries are fed by Lake Burien, stormwater runoff, and groundwater seeps.

SALMONID USE

The known freshwater distribution of anadromous salmonids is depicted in Appendix B, Figures 1-6. In Miller Creek, there are annual observations for the last eight years of adult coho spawning, and one report from the 1980s of a single sockeye adult observed (WDFW Spawning Ground Survey Database).

FACTORS OF DECLINE

FISH PASSAGE

An impassable cascade was identified at RM 1.0, an impassable fall at RM 1.9 and 2.5 by Williams (1975). A reconnaissance survey conducted by King County (Heller 1987a) did not identify any impassable barriers. Additionally, the SSHIAP database does not indicate that these barriers exist as of 1999.

RIPARIAN CONDITION

Only limited information was located that described site-specific riparian conditions along main-stem Miller Creek. A functioning riparian habitat along this stream is limited to the stream reaches in the creek where it drops over the top of the bluff down a steep ravine. Even in this area, residential housing encroaches on the stream. Consisting of a deciduous-dominated second-growth forest with some conifers and a shrub understory, the riparian zone in this reach is “Fair” according to the criteria contained in the report Appendix.

The riparian habitat does not meet criteria of properly functioning. The lack of adequate riparian habitat is a limiting factor to natural salmonid production.

Large Woody Debris

No specific information on historic amounts of LWD was located during the investigation for this report. Based on channel type, it is assumed that laterally-stable moderate to high gradient contained reaches of the lower mile supported dense stands of conifer including Douglas-fir, western red cedar, and western hemlock.

The potential for the natural recruitment of LWD throughout the Miller Creek subbasin is poor and land use activities effectively preclude the development of mature riparian stands.

No data was located that indicated the current condition of riparian zones with respect to organic matter and terrestrial insect recruitment. However, the lack of tall, mature trees is thought to effectively limit the supply of organic matter and terrestrial insects delivered to this subbasin.

HYDROLOGY

Impervious surfaces associated with single and multi-family residences are the primary contributors to high flows and large sediment loads in the tributaries and mainstem of Miller Creek.

SEDIMENT CONDITION

Outside of the ravine stream reach, the riparian communities along Miller Creek and its tributaries are composed primarily of young trees, shrubs, exotic species and ornamental plantings and none of the stream system is considered to have good bank stability.

Heller (1987a) noted landslides in the steep ravines of the lower basin as a significant problem that contributed silt and sediment to downstream reaches. Natural soil conditions in the ravine are likely promoting the landslides in this location that is then transported downstream by higher water events.

Heller (1987a) also noted significant sedimentation problems at the outlet to Tubs Lake, which was filled with sediment that reversed flow direction of roadway associated drainage ditches allowing runoff to discharge directly into the lake. He also found erosion problems associated with culverts and concrete-lined stream channel.

Impervious surfaces associated with single- and multi-family residences, commercial development and SeaTac Airport that reach 40 percent and are expected to be 50 percent when the land is fully built-out (Heller 1987a), are believed to be the primary contributors to high flows and large sediment loads in these creeks.

WATER QUALITY

Water quality is adversely impacted by the high percentage of impervious surfaces within the subbasin. The presence of domestic trash throughout the stream channel is both an aesthetic and water quality problem.

Miller Creek does not appear on the 1998 Department of Ecology 303(d) water quality violations list.

NON-NATIVE SPECIES

Animals

No exotic aquatic animal species in the subbasin were identified during the course of this investigation.

Plants

Reed canarygrass (*Phalaris arundinacea*) is found in localized reaches of stream channels throughout this subbasin. Other exotic plant communities in the riparian zone consist of Himalayan blackberries and willow species (*Salix spp.*), and numerous ornamental plantings associated with the residential communities.

HYDROMODIFICATION

No information was located that described site specific historical riparian conditions along the mainstem Miller Creek or any of its tributaries. In general, it is likely that vegetation in the Miller Creek subbasin was similar to that elsewhere in the Puget Sound region. There are numerous wetlands, bogs, small ponds and lakes in the upland areas that form the headwaters of the tributaries. A mixture of emergent wetlands probably characterized these areas or wet meadows intermixed with forested wetlands and uplands supporting Douglas-fir on the dryer sites. Riparian vegetation communities would have been similar to that described for the middle Green River in the vicinity of Soos Creek.

Heller (1987a) was unable to locate any unaltered streams in this subbasin. With the headwaters of all seven main tributaries in pipelines or roadside ditches, and major stream reaches of all the tributaries and mainstem channelized or otherwise modified, these creeks have been altered from their natural state. The lower three miles of the mainstem Miller Creek have been straightened, have a streamside-associated sewer line, and all LWD removed.

As is the case in many urbanized stream setting, the filling of wetlands has reduced natural stormwater storage capabilities of the subbasin and the construction of single family residences within the 100-year floodplain and associated flood control efforts has altered the stream channel in numerous locations. Because the land is largely built out, current peak flows in these creeks are likely to approximate future flows.

DES MOINES CREEK (09.0377)

PHYSICAL DESCRIPTION

STREAM COURSE AND MORPHOLOGY

Des Moines Creek drains an area of approximately 5.8 square miles of heavily urbanized lands. As is true with most independent tributary streams, Des Moines Creek originates from a diverse series of groundwater seeps on a plateau where it has a fairly low gradient. The creek drops through a steep canyon shortly prior to entering into Puget Sound.

Des Moines Creek has two major tributaries, two smaller tributaries and uncounted small diverse seeps. Inside the subbasin are also Bow Lake and the Northwest Ponds complex. The east fork (09.0377) has its origins from Bow Lake, while the west fork (09.0379) originates from the Northwest Ponds complex along the western edge of the Tyee Golf Course. Both forks merge on the grounds of the Tyee Golf Course. Both forks are fed by a combination of groundwater and surface runoff.

Previous studies (King County 1974 and 1987; METRO 1987 and 1989) conducted by King County have established that this subbasin has been severely degraded by urbanization. The habitat problems and processes identified in these studies include channel and bank erosion, degraded fisheries and flooding.

Stream habitats within Des Moines Creek have been surveyed and inventoried several times in recent years. The results of these studies are reported below.

SALMONID USE

The known freshwater distribution of anadromous salmonids is depicted in Appendix B, Figures 1-6. Juvenile coastal cutthroat trout, coho salmon and steelhead have all been recently observed in Des Moines Creek(King County 1997). Adult coastal cutthroat, coho and pink salmon have also been observed in Des Moines Creek (King County 1997). Juvenile hybrid rainbow/cutthroat trout have also been reported being captured in the creek.

FACTORS OF DECLINE

FISH PASSAGE

There are several known and/or potential fish passage barriers in Des Moines Creek. Table Near-shore-1 gives barrier name, location and type.

At Marine View Drive, there is a 4 x 6 foot box culvert that at almost all flows presents a velocity barrier to adult salmonids. During low flows, the shallow water depth may also pose a barrier. Finally, the gradient within this culvert is steeper at the upper end than the lower, which allows the collection of sediments in the lower end.

Table Nearshore-1. Fish Passage Barriers in the Des Moines Creek Subbasin.

Barrier Name	RM Location	Type/Comments
Marine View Drive Culvert	RM 0.4	Velocity and water depth barrier at most flows
Midway Treatment Plant Log and Concrete Weirs	RM 0.9	Partial barrier depending on stream flows
Tyee Golf Course Weirs	RM 2.1	Complete barrier, three 3- to 4- foot-high weirs

Source: King County 1997.

RIPARIAN CONDITION

A functioning riparian habitat along this stream is virtually nonexistent. The headwaters of all the two major tributaries (East and West forks) and the two minor tributaries originate in heavily urbanized areas.

The East Fork Des Moines Creek originates from Bow Lake and for the first half mile of its existence flows through buried pipes and finally surfaces in the vicinity of 26th Avenue South. The West Fork originates from a regional stormwater detention facility called the Northwest Ponds complex in the vicinity of the Tyee Golf Course. SeaTac airport straddles the boundary between the two forks and contributes flows to both through a complex series of subsurface drainage pipes.

The first functional riparian habitat is encountered downstream of South 200th Street where Des Moines Creek passes through a large wetland with a developed riparian zone before the creek enters a ravine at RM 1.85. At this point, the creek is paralleled by a service road that contains a sewer district trunk line. In many places, the service road functions as the stream bank. Only downstream of the Midway Sewage Treatment plant does the creek again have a stream adjacent riparian zone that provides limited function. In the vicinity of Marine View Drive (RM 0.4) the creek enters a 225-foot-long box culvert before entering Beach Park. Two buildings in this park are built directly over the stream.

No data was located that indicated the current condition of riparian zones with respect to organic matter and terrestrial insect recruitment. However, the lack of tall, mature trees is thought to effectively limit the supply of organic matter and terrestrial insects delivered to this subbasin.

The riparian habitat present consists primarily of young red alder and few coniferous trees. Himalayan blackberry, salmonberry, vine maple and Indian plum are the dominant species that are found along the streambanks.

The riparian habitat does not meet any criteria of properly functioning. The lack of adequate riparian habitat is a limiting factor to natural salmonid production.

Large Woody Debris

A 1993 survey (King County 1997) of LWD amounts identified only an average of seven to ten pieces per 100 yards. Most of the wood was described as small, located along the stream edge, or suspended over the channel. Debris complexes were described as “very limited” (King County 1997). Surveys conducted in 1986 and 1993 indicate that the amount of LWD may be decreasing (King County 1997).

The short- and long-term potential for LWD recruitment throughout the Des Moines Creek subbasin is poor, and land use activities effectively preclude the development of mature riparian stands.

HYDROLOGY

The hydrology problems in the Des Moines Creek subbasin are a classic example of an area that historically was covered with coniferous and deciduous forests and then developed to permit the construction of cities and their associated infrastructure. The understanding of the importance of the need to control stormwater quantity and quality, and the importance of rainfall to base flows, has lagged behind the development and urbanization process in this subbasin.

This subbasin now has an impervious surface area of 35 percent. Impervious surfaces associated with single- and multi-family residences and SeaTac International Airport are the primary contributors to high flows and large sediment loads in these creeks. The existing stormwater retention and detention infrastructure is not sufficient to control the increased frequency and duration of storm event peak runoff flows into Des Moines Creek. These increased flood flows have resulted in channel erosion and the scour of spawning gravels with a resultant loss of spawning areas.

While impervious surface area is expected to increase by almost 58 percent the combined regional detention and water diversion recommendations contained in the Des Moines Creek Basin Plan (King County 1997) for flow control could be designed to reduce flood frequency through the diversion of flood lows associated with frequent but small flood events.

SEDIMENT CONDITION

The degree of damage to hillslopes from past land use activities is significantly less in Des Moines Creek than many of the other Puget Sound independent tributaries in this chapter. This is primarily due to the stream’s geologic origin and history. While most stream systems are formed in advance glacial outwash deposits, Des Moines Creek was formed largely in recessional glacial outwash formations. As a result, erosion (and especially hillslope erosion from increased storm-water flows) has resulted in some loss of the overlying soil layers, but the catastrophic downcutting seen in many other systems is not evident here.

That is not to say that there are not problem areas in Des Moines Creek. Three hillside failures are present just upstream of road fill of Des Moines Memorial Way (between RM 0.45 and 0.55). During the February 1996 storm, debris flows from these bank failures carried substantial amounts of sediments several hundred feet downstream.

There is also evidence of hillslope erosion sites that appear to be the result of road end stormwater discharges. The largest known of these sites is the expansion of the natural channel at RM 1.35 where additional runoff from 18th Avenue South enters the creek. Thirteen bank erosion or slope failure problems were identified during a 1993 habitat survey (King County 1997).

Two conditions that adversely effect stream channel condition: the confinement of the original stream floodplain by fill that surrounds a sewer trunk line and the access road exacerbate channel conditions in this ravine. This creates a situation where storm flows scour stream sediments down to rock and clay deposits that while relatively stable, little or no suitable pools are available that would allow for salmonid rearing. Of the 133 residual pool depths identified during a 1993 stream habitat inventory, the median pool depth was 0.9 feet and the substrate consisted mostly of 15 to 80 mm sands and gravels.

Outside of the ravine, the stream channel conditions can be summarized as composed of low-gradient riffles with a few lateral scour pools and shallow pools. Sediments varies from silt and sands to small gravels, boulders and large areas of exposed clay (the later two found primarily in the incised ravine).

WATER QUALITY

The quality of water in Des Moines Creek is also directly linked to the land use activities in the subbasin. Because of the urbanization throughout the subbasin, the nonpoint source pollution from anthropogenic activities is the primary source of pollutants entering the creek.

Des Moines Creek appears on the EPA 1998 303(d) list for fecal coliform violations. The source of the elevated levels of fecal coliforms may come from failing septic systems, leaking sewer lines, illicit sewer connections, birds (geese) residing on the Tyee Golf Course, domestic animals or some combination of any of the previous examples. The presence of elevated fecal coliform levels is in itself not necessarily detrimental to salmonid production, but may be an indicator of other urbanization-associated problems.

Water quality problems that have been identified in the Des Moines Creek subbasin include the following:

- Previous studies have indicated that the Tyee Golf Course may be contributing excess phosphorus and nitrogen to the creek.
- Turbidity and suspended solids concentrations increase substantially during storm events. Some likely sources include surface runoff, streambank erosion and streambank failure. The increase in concentrations also suggest high levels of gravel scour and deposition of fines.
- Stream water temperatures exceed the optimal upper temperature limit of 14^{o}C for salmonids. They also exceeded the current Washington State standard of 22^{o}C on numerous occasions from April through September 1996. However, they did not reach the lethal limit of 22^{o}C. during that same time period.

- Dissolved oxygen (DO) concentrations are directly linked to stream water temperature (Boyle's Law) and they fell as low as 2 mg/L in the West Fork and typically to 7 mg/L in the East Fork (measured upstream of the Tyee Golf Course weir). While DO levels recovered before the waters reached the salmonid fish zone they are of concern.

It should be noted that both the Port of Seattle (SeaTac Airport) and the City of Des Moines have ongoing water quality monitoring programs in Des Moines Creek or stormwater outfalls into the creek.

LAND USE

The effects of urbanization that have occurred on the natural and historic riparian habitats in Des Moines Creek are as profound as anywhere in the urbanized Puget Sound ecoregion. Approximately 35 percent of the subbasin is currently covered with impervious surfaces (King County 1997). This in turn causes elevated flow levels following storm events, accelerated rates or streambed erosion and sedimentation, aquatic habitat degradation and elevated pollutant levels. Under future conditions, it is estimated that 46 percent of this subbasin will be covered by impervious surfaces.

NON-NATIVE SPECIES

Animals

The only non-native fish species identified in this subbasin are pumpkinseed sunfish. The likely source of these fish is Bow Lake and/or the Tyee Golf Course Ponds. No other non-native aquatic animal species in the subbasin were identified during the course of this investigation.

Plants

Reed canarygrass (*Phalaris arundinacea*) is abundant throughout this subbasin. Other exotic plant communities in the riparian zone consist of Himalayan blackberries and willow species (*Salix spp.*), and numerous ornamental plantings associated with the residential communities.

HYDROMODIFICATION

No information was located during the course of this investigation that showed current vs. historic stream channel. However, given the extensive residential and commercial development and the presence of regional stormwater detention facilities, several thousand of feet of pipes and culverts in this subbasin there is little doubt that the streambed has been relocated in some reaches.

FAUNTLEROY CREEK (09.0361)

PHYSICAL DESCRIPTION

STREAM COURSE AND MORPHOLOGY

With a drainage basin of approximately 98 acres, Fauntleroy Creek is a small independent tributary stream to Puget Sound. It is bounded by Williams and Brace Points and enters Puget Sound in the vicinity of the Vashon-Fauntleroy Ferry Dock. Similar to many of these small independent creeks, Fauntleroy Creek originates from a diverse series of groundwater seeps and bogs on the plateau, most of which are in or adjacent to Fauntleroy Park. With six small low-gradient tributaries, the creek traverses the plateau before it drops through a steep canyon, losing approximately 300 feet in elevation shortly prior to entering into Puget Sound in Fauntleroy Cove.

SALMONID USE

The known freshwater distribution of anadromous salmonids is depicted in Appendix B, Figures 1-6. Juvenile and adult coho salmon have been observed to spawn and rear respectively in Fauntleroy Creek (Seattle, In Progress). No information was obtained that indicates utilization by other salmonid species.

FACTORS OF DECLINE

FISH PASSAGE

There are several known and/or potential fish passage barriers throughout Fauntleroy Creek. A partial barrier exists at the edge of tidewater where the creek flows over a rock revetment that requires anadromous fish to jump at least one foot. A series of 6- to 12-inch anthropogenic weirs in the lower reach may also be partial barriers. At approximately RM 0.2, there is a 14-inch cascade that is a barrier to all anadromous salmonids. Approximately 410 feet upstream of this initial barrier is a 2-foot-high, 3-square box structure with a sheer water drop of six feet that is also a barrier.

RIPARIAN CONDITION

The effects of urbanization that have occurred on the natural and historic riparian habitats in Fauntleroy are profound. A comprehensive inventory of riparian habitats is currently not available. However, the Fauntleroy Watershed Plan (Seattle, In Progress) does provide some preliminary insight into the condition of the riparian zone of Fauntleroy Creek. That work breaks the creek into the following critical stream reaches:

- Tidewater to Initial Fishway;
- Initial Fishway to 45th Ave S.W.;
- 45th Ave. S.W. to Kilbourne Park; and
- Kilbourne Park to Fauntleroy Park.

Each reach is assessed for riparian habitat. Reaches 1 and 3 were determined to NOT have adequate vegetation in the riparian zone. The native vegetation in Reach 2 was assessed as good to excellent. Reach 4 was assessed as a mixture of good to excellent native vegetation in the lower portion, while the upper portion was dominated by non-native and invasive species. The riparian habitat present consists primarily of young-to-maturing red alders and few coniferous trees. In Reach 1, property owners have expressed concern that any vegetation not block their views. Of the native plants found in the shrub canopy zone, salmonberry, vine maple, stink current, hazelnut, oceanspray, twinberry, red huckleberry, osoberry and Indian plum are the dominant species that are found along the streambanks. Numerous non-native species are found throughout the stream reaches (see Non-Native Species, below).

No data was located that indicated the current condition of riparian zones with respect to organic matter and terrestrial insect recruitment. However, Seattle (In Progress) did note pollution-intolerant (Class 1) macroinvertebrates were present in all four reaches. However, while the macroinvertebrates are present, they do not appear to be in sufficient numbers to support populations of salmonid fry (Seattle, In Progress). The lack of tall, mature trees is thought to effectively limit the supply of organic matter and terrestrial insects delivered to this subbasin.

The riparian habitat does not meet any criteria of properly functioning. The lack of adequate riparian habitat is a limiting factor to natural salmonid production.

Large Woody Debris

LWD amounts have not been completely surveyed, but Seattle (In Progress) noted that LWD was “sparse” throughout the stream. The short- and long-term potential for LWD recruitment throughout Fauntleroy Creek is poor, and land use activities effectively preclude the development of mature riparian stands.

HYDROLOGY

Kendra (1989) measured seasonal flows in June and August of 1988 at several locations throughout the stream. Flow was 0.1 cfs downstream of the headwater tributaries and 0.3 to 0.4 cfs at the three downstream sampling sites. Seattle (In Progress) stated that many of the current culverts are significantly undersized for the conveyance of current flood flows.

The hydrology problems in the Fauntleroy Creek are a classic example of an area that was historically covered with coniferous and deciduous forests, then developed to construct city infrastructure, As a result, a significant portion of the land in the subbasin becomes covered with effective impervious surface areas.

SEDIMENT CONDITION

Streambanks in most instances appear stable, with some streambed incision noted in a few reaches. There is also evidence of hillslope erosion sites in the ravine.

Confinement of the original stream floodplain by channelized stream reaches, roads, and road crossings create storm flows that scour stream sediments, causing sedimentation in downstream reaches and embedded gravels. Many of the pools associated with fishways in the lower reaches routinely fill with sediments and their usefulness as fishways is diminished or lost.

WATER QUALITY

The quality of water in Fauntleroy Creek is also directly linked to the land use activities in the subbasin. Because of the urbanization throughout the subbasin, the nonpoint source pollution from anthropogenic activities is the primary source of pollutants entering the creek. Water quality is adversely impacted by the high percentage of impervious surfaces within the subbasin and the presence of domestic trash throughout the stream channel is both an aesthetic and water quality problem.

Fauntleroy Creek appears on the EPA 1998 303(d) list for fecal coliform violations. The source of the elevated levels of fecal coliforms may come from failing septic systems, leaking sewer lines, illicit sewer connections, birds (geese) residing Fauntleroy Park, domestic animals or some combination of any of the previous examples. METRO (1988) examined fecal contamination in Fauntleroy Creek and found higher levels in summer than those in winter. The presence of elevated fecal coliform levels is in itself not necessarily detrimental to salmonid production, but may be an indicator of other urbanization-associated problems.

Kendra (1989) examined water quality in Fauntleroy Creek and found relatively uniform results from the headwaters to the mouth for temperature, pH, conductivity, dissolved oxygen, phosphorus and total suspended solids. The sample results did not indicate any concerns that may impact salmonids.

LAND USE

Impervious surfaces associated with single- and multi-family residences are the primary contributors to high flows and large sediment loads in these creeks. While no information was located that provided the amount of effective impervious surface area in the basin, based on adjacent subbasins it is expected to exceed 20 percent.

Non-Native Species

Animals

There were no reports of exotic fish species identified in this subbasin during the course of this investigation.

Plants

Reed canarygrass (*Phalaris arundinacea*) is abundant throughout this subbasin. Other exotic plant communities in the riparian zone consist of Himalayan blackberries, English laurel, English ivy, English holly, clematis, polygonum, morning glory, nightshade, and giant hogweed along with numerous ornamental plantings associated with the residential communities.

No information was located during the course of this investigation that showed current vs. historic stream channel. However, given the extensive residential and commercial development along with at least five road crossings, several hundred feet of channelized streambank and several hundred feet of pipes and culverts in this subbasin there is little doubt that the streambed has been relocated in some reaches.

HYDROMODIFICATION

In all four reaches, various distances of Fauntleroy Creek were contained in culverts, channelized though property right-of-ways and along roads.

KEY FINDINGS AND HABITAT-LIMITING FACTORS

- There is currently only very limited utilization by anadromous salmonids in these streams.
- The impervious surface area of many of these subbasins is expected to range from 15 to 58 percent in the near future.
- Current and future development is (and will likely continue) generating increased stream flows, channel instability problems, excessive sediment loadings, instream and riparian habitat degradation.
- Wetlands played an important function in maintaining streamflows in many of these small streams. Many of these wetlands have been partly or completely eliminated, and the remaining wetlands are continuing to be degraded.
- Water quality is adversely impacted by the high percentage of impervious surfaces within these subbasins, and the presence of domestic trash throughout the stream channels is both an aesthetic and water quality problem.
- LWD is absent or deficient throughout these streams. Current land use activities effectively preclude any short- or long-term recruitment of LWD into most of these streams. The only passive source of LWD recruitment potential is generally in the stream reaches that cascade down the bluffline.
- Known and suspected anthropogenic barriers limit access to spawning and rearing habitat.
- Both the quality and quantity of gravels in the streams limit spawning success and, to a lesser degree, juvenile rearing habitat.
- Flood flows due to increased impervious surfaces adversely impact successful salmonid incubation.
- Riparian habitats are degraded and in poor condition.
- Generally, habitat trends are showing strong indications of a downward trend.

DATA GAPS

- Comprehensive barrier surveys in this group of subbasins need to be initiated and/or updated.
- Comprehensive baseline riparian habitat surveys should be initiated.
- Aquatic invertebrate populations should be monitored.
- An inventory of LWD should be initiated.
- The level and impacts to salmonids from contaminated surface water is unknown.

LIST OF TABLES

Table Nearshore-1: Fish Passage Barriers in the Des Moines Creek Subbasin

3.13 VASHON AND MAURY ISLANDS SUBBASIN

Physical description ... 2
Stream Course and Morphology ... 2
Salmonid Use ... 5
Factors of Decline ... 5
Land Use ... 5
hydrology ... 6
Water Quality ... 7
Non-Native Species ... 7
Key Findings and Identified Habitat-Limiting Factors ... 7
Data Gaps ... 8
Early Action Recommendations ... 8
Individual Freshwater Streams ... 8
Mccloud Creek (1) ... 8
Sylvan Beach Creek (2) ... 9
Water Wheel Creek (7) ... 10
Mccormick Creek (10) ... 10
Baldwin Creek (11) ... 11
Shinglemill Creek and Its Tributaries (12) ... 12
Unnamed Stream (13) ... 13
Ober Creek (15) ... 14
Skeeder Creek (16) ... 14
Cove Creek (17) ... 15
Leo's Creek (19) ... 16
Robinwood Creek (20) ... 17
Green valley Creek (21) ... 18
Christianson (Jod) creek (23) ... 19
Unnamed Stream (24) ... 20
Unnamed Stream (26) ... 21
Unnamed Tributaries (27, 28 and 29) ... 22
Bates Creek (30) (h2) ... 22
Sealth Creek (32) ... 23
S-1 and s-2 Creeks (33 and 35) ... 24
Spring beach Creek (34) ... 25
Slaighters Creek (36) ... 25
Tahlequah Creek (37) ... 26
Shawnee Creek (40) ... 27
Fisher Creek (41) ... 28
Judd Creek (42) ... 29
Tsugwalla Creek (43) ... 29
Raab's Lagoon Creek (44) ... 30
Mileta Creek (45) ... 31
Ellis Creek (62) ... 32
Ellisport Creek (63) ... 33
Beall Creek (64) ... 34
Gorsuch Creek (65) ... 35
Dillworth Creek (66) ... 36
Glen Acres Creek ... 37

3.13 VASHON AND MAURY ISLANDS SUBBASIN

PHYSICAL DESCRIPTION

STREAM COURSE AND MORPHOLOGY

The larger of the streams in terms of stream length, flow and drainage basin, on Vashon and Maury Islands (the Island) typically originate from small, diverse series of groundwater seeps in the upland areas of the Island. In these reaches, the streams are generally low gradient and meander across the landscape. These upland areas are usually between 300 to 500 feet above sea level. The larger stream systems (such as Judd and Shinglemill Creeks) flow through an extensive system of long, high-gradient ravines before entering the Puget Sound estuary. The streams that have smaller drainage areas and lower flows may also originate from upland seeps and/or seeps and springs present inside of the steep incised ravines that drop through the bluffline that rings the Island. All of these streams drop through steep (gradients of 10-15 percent) stream channels before they enter the Puget Sound estuary with little or no freshwater to saltwater interface.

For many of the streams on the Island, basic habitat quality data has not been collected. Much of the data and information in this chapter was collected by survey crews from Washington Trout (In Progress) from surveys conducted during the summer of 2000. Most of their data is qualitative and was subject to the best professional judgement of the survey crews involved in the collection. Unless otherwise noted, the information below is attributed to Washington Trout (In Progress).

Williams identified only a few of the Island streams, and Ames (1981) identified 28 streams with 18 tributaries on Vashon Island and 11 tributaries with 4 tributaries on Maury Island. Because many of the creeks were not identified by these sources, a numbering system devised by Washington Trout is utilized here. That system begins at the north end of Vashon Island with the number “1” and assigns individual independent creeks a successively higher number as one moves counter-clockwise around the Island. Where known, WRIA numbers from Williams (1975) and Ames (1981) are included in parentheses in table Vashon-1. Stream numbers and local names, where known, are shown in the table Vashon-1 and on the Fish Distribution Maps located in the Report Appendix.

Table Vashon-1. Vashon-Maury Island Streams, Fish Presence, Barriers and Water Withdrawals.

Stream Number	Name	Species of Fish Present	Barrier Present	Water Withdrawals	Comments
1	McCloud Ck.	None	Yes–mouth	Yes - Private	
2	Sylvan Ck.	None	Yes-mouth	Yes- Private	
3	Corbin Beach Ck.	None	No data		
4	Unnamed	None	No data		
5	Unnamed	None	No data		
6	Unnamed	None	No data		
7	Water Wheel Ck.	None, but possibly historic	Yes–bulkhead at mouth & diversion	Yes--Private	Mouth altered by water wheel diversion
8	Unnamed	None	No data		
9	Cedarhurst Landing Ck.	None	No data		
10	McCormick Ck.	Cutthroat – juv.	Yes–Burma Dr	Historic	Old diversion structure may be barrier.
11	Baldwin Ck.	Cutthroat – juv. Coho – juv.	Yes – Cedarhurst Rd.	Yes--Private	
12 (0159) 12 –A 12 – C 12 – D 12 – E	Shinglemill Ck Needle Ck J + Y Creek Pit Bull Ck. Unnamed	Cutthroat–juv. & adult. *O. mykiss* – juv. & adult Coho - adult Coho – juv. & adults Cutthroat – juv. Cutthroat – juv. Cutthroat – juv Cutthroat – juv.	 Yes Yes-constructed Falls Yes – natural falls	Yes – Westside Water District Historic Yes - private Historic	Some mass wasting sites in ravines. Headwater diversion, possible origin of mass wasting
13	Unnamed	None	Yes–bulkhead	None identified	
14	Unnamed	None	No data	No data	
15 (0158)	Ober Ck.	Possible cutthroat	Yes – Ober Drive	None identified	Dredged every 10+/- years by homeowners
16 (0157)	Skeeder Ck.	None	Possible - bulkhead	Yes-- multiple private	
17	Cove Ck.	None	None identified	Historic	
18	Unnamed	None	None identified	Nodata	
19	Leo's Ck.	None	Possible – debris barrier at mouth	Yes--Multiple private	
20 (0155)	Robinwood Ck.	Cutthroat juvenile	None identified	None identified	County landfill in basin
21 (0154)	Green Valley Ck.	None	Yes – Dam near mouth	Historic	Old water wheel
22	Unnamed	None	No data	No data	
23 (0153)	Christianson (Jod) Ck.	Cutthroat – juv *O. mykiss* – juv.	Yes – Redding Beach Rd.	Yes – Multiple private systems	
24	Unnamed	None	Possible at mouth. Yes-Redding Rd. culvert	None identified	Hand dug water diversion near mouth
25	Unnamed	None	No data	No data	
26	Unnamed	None	Possible at mouth	None identified	
27	Unnamed	None	Yes-bulkhead	None identified	
28	Unnamed	None	Yes-bulkhead	None identified	
29	Unnamed	None	Yes-bulkhead	None identified	
30 (0152)	Bates Ck.	Cutthroat juvenile	Probable-culverts	None identified	
31	Paradise Cove Ck.	None	No data		
32 (149)	Sealth Ck.	None	Yes-bulkhead	None identified	
33	S 1 Ck.	None	Sand and debris bar at mouth	None identified	

Table Vashon-1. Vashon-Maury Island Streams, Fish Presence, Barriers and Water Withdrawals (contd.).					
34	Spring Beach Ck.	None	Yes–culvert and bulkhead at mouth	None identified	
35	S 2 Ck.	None	Sand and debris bar at mouth	None identified	
36	Slaighters Ck.	None	Yes-pipe at Pohl Rd. & ponds.	None identified	Impacted by ponds at mouth.
37 (0147)	Tahlequah Ck.	Cutthroat Juvenile	Yes on tributary "B"	None identified	½ to ¾ - acre pond with standpipe outlet
38	Chen Ck.	None	No data	No data	
39	Lost Lake Ck.	None	No data	No data	
40	Shawnee Ck.	Cutthroat Juvenile	Yes–bulkhead and pipes	None identified	
41 (0139)	Fisher Ck.	Cutthroat juvenile	Possible culvert barrier at 232nd St.	Yes	Burton Water Co. present in upper reaches
42 (0129)	Judd Ck.	Chinook, Coho & chum–adults Cutthroat – juv.	Needs to be surveyed.	Needs to be surveyed	Not surveyed by Washington Trout
43 (0126)	Tsugwalla Ck.	None	Yes – mouth and culvert	None identified	Stream flows thru 3 ponds
44	Raab's Lagoon Ck.	None	Possible at bulkhead	None identified	
45	Mileta Ck.	Cutthroat – juv.	Yes-culvert	None identified	
46	N. Dockton Ck	None	No data	No data	
47	Mid Dockton Ck.	None	No data	No data	
48	S. Dockton Ck.	None	No data	No data	
49	Unnamed	None	No data	No data	
50	Unnamed	None	No data	No data	
51	Unnamed	None	No data	No data	
52	Unnamed	None	No data	No data	
53	Unnamed	None	No data	No data	
54	Unnamed	None	No data	No data	
55	Unnamed	None	No data	No data	
56	Unnamed	None	No data	No data	
57	Maury Island Park Ck.	None	No data	No data	
58	Unnamed	None	No data	No data	
59	Unnamed	None	No data	No data	
60	Unnamed	None	No data	No data	
61	Unnamed	None	No data	No data	
62	Ellis (Tramp Harbor) Ck.	Cutthroat Juvenile	Yes - Culvert & dam	Yes – Municipal District 19	Water diversions into ponds
63	Ellisport (Fuller) Ck.	Cutthroat Juvenile	Partial barrier	None identified	Soil contamination at mouth
64	Beal Ck.	Cutthroat juvenile	Yes – Water Station	Yes – Municipal District 19	
65	Gorsuch Ck.	Cutthroat Juvenile	Yes – several natural and anthropogenic	None identified	Sewage treatment plant
66	Dillworth Ck.	Cutthroat juvenile	Yes -Dillworth Road	None identified	
67	Glen Acres Ck.	None	Yes - bulkhead	None identified	
68	Unnamed	No data	No data	No data	
69	Unnamed	No data	No data	No data	
70	Unnamed	No data	No data	No data	
72	Unnamed	No data	No data	No data	
73	Unnamed	No data	No data	No data	
74	Unnamed	No data	No data	No data	

SALMONID USE

The known freshwater distribution of anadromous salmonids for Vashon and Maury Islands is depicted in the Fish Distribution Maps located in the Report Appendix. Known distribution was obtained from the Washington Department of Fish and Wildlife Spawning Ground Survey Database, StreamNet, SASSI, and the year 2000 survey conducted by Washington Trout.

Many of the cutthroat observations are of juveniles. Coastal cutthroat trout are a subspecies of cutthroat trout (*O. clarkii*) and are thought to have four life history forms. Since it is possible for all forms to occur in a stream at once and since it is not possible to distinguish between resident and anadromous forms, we have chosen to use the term coastal cutthroat in this document.

O. mykiss has both resident (rainbow trout) and anadromous (steelhead) life history forms. Juvenile observations of *O. mykiss* face similar challenges to that of coastal cutthroat. Rather than make attempts to distinguish between the two forms we have chosen to use the term *O. mykiss* in this document.

In many cases, the documented observations of salmonids (resident and anadromous) likely underestimates the actual distribution. This is particularly true of coastal cutthroat trout and coho.

A map illustrating the presumed freshwater distribution of salmonids (but not coastal cutthroat) is depicted in the Fish Distribution Maps located in the Report Appendix.

All of these creeks flow directly into Puget Sound and as such are believed to provide an important localized freshwater input into this area of Puget Sound. No data are available detailing the complete utilization by juvenile, sub-adult or adult salmonid usage of these marine areas. However juvenile and adult coho, chinook, and coastal cutthroat trout have been observed at numerous points along the marine shorelines (Kerwin 2000).

FACTORS OF DECLINE

LAND USE

Vashon and Maury Islands have experienced significant and substantial changes since historic times (prior to 1860). Virtually all of the original pre-settlement wetland forests of Sitka spruce and western red cedar, and upland forests of western hemlock and Douglas fir within the subbasin were logged and removed by 1897 (USGS 1900). In many cases, the forests have been logged a second time and then the land cleared.

Currently, land use throughout the Island is typically a mixed rural residential, small scale agriculture and service related commercial development. The development of residential and commercial areas has resulted in the alteration of the natural drainage patterns, but no data was located that provided an indication of total or effective impervious surfaces in any of the Island's stream subbasins.

HYDROLOGY

Hydrology in many of these basins has exhibited changes due to development of upland areas and water withdrawals for domestic and agricultural use by private landowners and water districts. Known flows of selected creeks is shown in table Vashon-2

Table Vashon-2. Stream Flows of Selected Streams on Vashon-Maury Islands.

Stream Name	Flow (cfs) Low	Flow (cfs) High	Base Flow (cfs)
Beall Creek (64)	0.01	4.28	0.3-1.0
Mileta Creek (45)	0	91	0.0-2.0
Fisher Creek (41)	0.6	ND	1.0
Green Valley Creek (21)	0.44	ND	0.44
Paradise Cove Creek[1] (31)	0.12	0.45	[1.]
Tahlequah Creek (37)	0.3	ND	0.5
Judd Creek (42)	2.25	ND	2.0
Upper Judd Creek (42)	1.5	ND	1.5-2.0
Needle (Shinglemill) Creek (12A)	1.4	ND	1.5-2.5

ND = Not Determined. The data obtained exceeded the range of the discharge rating curve.
1. Flows may not be accurate due to data collection limitations. (King County. 1998)

Selected streams in WRIA 15, and specifically on Vashon Island, were closed to water withdrawal by the Washington Department of Ecology in 1988. These streams were closed in as a part of an Instream Resources Protection Program (IRPP) under the authority of Chapter 173-515 WAC. The streams closed are the mainstem reaches of Judd, Fisher and Christianson (Jod) Creeks and Shinglemill Creek and all of its tributaries. No minimum instream flows have been established for streams on the Island.

A survey that compared permitted water withdrawal quantities with actual water withdrawal quantities of the six (Burton Water Company, Dockton Water Association, Heights Water Association, MMC, Water District No. 19 and the Westside Water Association) water purveyors indicated two (Heights Water Association and Water District Number 19) exceeded maximum permitted quantities for instantaneous water withdrawal (Seattle King County Health Department 1995). In that same survey, three (Dockton Water Association, Heights Water Association, and Water District No. 19) of four (Dockton Water Association, Heights Water Association, MMC, and Water District No. 19) water purveyors exceeded the permitted maximum annual water withdrawal quantities.

The exact number of private surface water withdrawals and wells on the Island is not known. A search of 243 water rights, as listed in the WSDOE Water Rights Application Tracking System, showed 178 to be surface water, 56 groundwater and 9 unknown water withdrawals. While there are procedures for private wells to be tagged and entered into the South King County Health Department database, many of the older wells and surface water withdrawals do not appear in that database.

WATER QUALITY

Surface water quality sampling occurred at eight stream stations on Vashon Island on approximately 14 occasions (monthly) between August 1991 and September 1992 as part of the Vashon-Maury Island Groundwater Management Plan (1998) effort. The eight streams and their watershed areas are given in table Vashon-3. Freshwater samples were collected near the staff gauge in the middle of the creek near the mouth. Samples were analyzed for temperature, pH, coliforms (fecal, total), metals, chloride, nitrate-N, and sulfate. In addition, the Judd Creek site was sampled for volatile organic compounds, pesticides, and PCBs in August and September 1991. Results are presented in this section for temperature, pH, metals, and organics for purposes of assessing potential factors of decline for salmonids.

Table Vashon-3. Streams and Drainage Areas for Water Quality Sampling Stations.

Stream (Station Name)	Drainage Area (Acres)
Beall Creek	211
Fisher Creek	1,549
Green Valley Creek	762
Judd Creek	3,149
Mileta Creek	700
Paradise Cove Creek	200
Shinglemill (Needle) Creek	1,996
Tahlequah Creek	780

A summary of the water quality testing results in this survey indicates that most metals were below standards on most occasions. Cadmium, copper and zinc exceeded acute standards on one occasion at between one and four locations. With the exception of lead, the mean values of all metals were below chronic levels at all stations. Elevated lead levels (above the chronic standard) occurred on several occasions at Beall, Fisher and Mileta creeks.

Water was sampled at the Judd Creek site and analyzed for volatile organic compounds, pesticides, and PCBs in August and September 1991. All parameters were below detectable levels on both occasions.

NON-NATIVE SPECIES

There are numerous non-native plant species throughout these subbasins, but none appear to be a fundamental habitat-limiting factor to natural salmonid production at this time.

KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- Surface water is used for domestic purposes and demand is highest when instream flows are lowest.
- There are numerous anthropogenic barriers to anadromous fish migration on streams within this subbasin.
- Mass wasting and streambed scour may be limiting natural production of salmonids in Shinglemill Creek.

DATA GAPS

- There are no dissolved oxygen, turbidity or total suspended solids data for Island streams. There is no continuous temperature data, so it was not possible to determine maximum water temperatures. Available metals data is only for total metals; therefore, it was not possible to make comparisons with dissolved metal standards. There are no data available for storm conditions.
- There has not been a comprehensive barrier assessment conducted.
- There is not a comprehensive base line habitat survey for all Island streams.
- The loss of stream channel due to channelization has not been quantified.
- Actual, instantaneous water use from subbasin streams is not known.
- A water use and water level monitoring program should be established.
- Minimum instream flows are not identified on Island streams where private and municipal water withdrawals occur.
-

EARLY ACTION RECOMMENDATIONS

- Conduct a detailed assessment of the existing stream habitat conditions for use in evaluating enhancement opportunities and constraints.
- Conduct a comprehensive fish barrier and habitat assessment project to identify access barriers and the quantity and quality of habitat upstream throughout Vashon-Maury Islands.
- Screen all water diversions properly to avoid fish entry.
- Conduct an island wide investigation of (legal and illegal) surface and ground water withdrawal. As a part of this investigation examine the impacts of surface and groundwater withdrawals on stream subbasins and evaluate the effects on salmonids.

INDIVIDUAL FRESHWATER STREAMS

Varying amounts of information and data are available on the different freshwater stream systems of the Island. Information obtained on 38 of them is presented below.

MCCLOUD CREEK (1)

FISH PASSAGE

The creek enters the Puget Sound estuary via a 5-foot-high drop from a boxed wooden pipe that is a barrier. This structure eliminates anadromous fish access.

LAND USE

Land use is a mixture of forest and rural residential.

RIPARIAN CONDITION

Deciduous trees dominate the riparian habitat of this small stream along with grasses and brush such as salmonberry, Himalayan blackberry and thimbleberry. Very few coniferous trees are present. Stream channel complexity is provided by abundant amounts of tree limbs and brush with lessor amounts of logs. Approximately 60 percent of the stream is in a shaded condition.

SEDIMENT CONDITION

The pool-to-riffle ratio is approximately 30:70. Overall, substrate types include gravel (20 percent), sand (60 percent), and mud (20 percent).

HYDROLOGY

No information was located on stream hydrology. There is a private well house on the mainstem.

HYDROMODIFICATION

The obvious hydromodification is the boxed wooden pipe where the creek enters saltwater. A footpath along the left bank locally limits lateral stream migration.

SYLVAN BEACH CREEK (2)

FISH PASSAGE

The creek enters the Puget Sound estuary via a 4-foot high drop through a bulkhead. This drop is a complete barrier and eliminates anadromous fish access.

LAND USE

Land use is a mixture of forest and rural residential.

RIPARIAN CONDITION

Only limited information was available about current riparian conditions of this small creek. Trees were described as sparse, shrubs and grasses as moderate. The percentage of the stream afforded shading is approximately 50 percent. Instream structure of any type was described as sparse and solely from deciduous trees.

SEDIMENT CONDITION

The pool-to-riffle ratio is approximately 20:80. Substrate types include gravel (50 percent) and sand (50 percent).

HYDROLOGY

No information was located on stream hydrology. A private water tank is located over a spring on the mainstem.

WATER WHEEL CREEK (7)

FISH PASSAGE

The creek enters the Puget Sound estuary via a 5-foot high drop from a bulkhead. This bulkhead is a barrier that eliminates anadromous fish access. Further upstream, a 2-foot-high diversion dam funnels the stream flow through a water wheel and this is a probable barrier at some flows.

LAND USE

Land use is a mixture of forest and rural residential.

RIPARIAN CONDITION

In the lower 300 feet, English ivy dominates the stream-associated riparian habitat. Upstream of this point, the stream enters a steep, incised ravine where second-growth deciduous and coniferous trees are present. Instream channel complexity is provided by moderate amounts of logs, rootwads, tree limbs and brush. Approximately 10 percent of the stream is in a shaded condition.

SEDIMENT CONDITION

The pool-to-riffle ratio is approximately 10:90. Substrate types include gravel (50 percent) and sand (50 percent). Some natural erosion is occurring at points approximately 800 feet upstream of the creek mouth where a diverse series of small seeps are eroding unconsolidated soils.

HYDROLOGY

No information was located on stream hydrology. There are two water tanks that sit on springs about 300 feet upstream of the creek mouth.

MCCORMICK CREEK (10)

FISH PASSAGE

A culvert underneath Burma Drive that is perched approximately 2 feet high at its downstream end is believed to be a barrier to upstream fish migration. Approximately 80 feet upstream of Burma Drive there is a water diversion structure that is also believed to be a barrier. Finally, further upstream approximately 220 feet is a 4-foot-high drop from a natural logjam that is also believed to be a barrier to upstream fish migration.

LAND USE

Land use is a mixture of forest and rural residential.

RIPARIAN CONDITION

No quantitative data was available to indicate riparian conditions of this system. Deciduous trees dominate the riparian habitat with moderate numbers of conifers. Stream channel complexity is provided by moderate amounts of structure such as logs, rootwads, limbs and brush. Approximately 60 percent of the stream is in a shaded condition.

SEDIMENT CONDITION

The pool-to-riffle ratio is approximately 40:60. Substrate types include boulder (5 percent), cobble (15 percent), gravel (30 percent), sand (40 percent), and mud (10 percent).

HYDROLOGY

No information was located on stream hydrology. A capped well and water system are located on the mainstem creek. There is an abandoned private potable water supply system on this creek.

BALDWIN CREEK (11)

NOTE: The WDNR hydrolayer currently has this stream mapped as a tributary to Shinglemill Creek. That is incorrect. The creek enters the Puget Sound estuary directly, albeit via the alluvial fan of Shinglemill Creek.

FISH PASSAGE

Coho salmon juveniles and coastal cutthroat trout juveniles have been observed in this creek. A 2-foot-high perched culvert and associated concrete energy dispersion apron at Cedarhurst Drive is believed to be a barrier to upstream salmonid migration.

LAND USE

Land use is a mixture of forest and rural residential.

RIPARIAN CONDITION

The riparian habitat has approximately equal amounts of coniferous and deciduous trees along with an understory of brush such as salmonberry, Himalayan blackberry, salal and stinging nettle. Stream channel complexity is provided by abundant amounts of tree limbs, rootwads, logs and brush. Approximately 80 percent of the stream is in a shaded condition.

SEDIMENT CONDITION

the pool-to-riffle ratio is approximately 40:60. substrate types include cobble (10 percent), gravel (40 percent), sand (40 percent), and mud (10 percent).

HYDROLOGY

No information was located on stream hydrology. There is a private well house on the mainstem.

SHINGLEMILL CREEK AND ITS TRIBUTARIES (12)

FISH PASSAGE

This stream system is the second-largest subbasin on the Island with a drainage area of 1,966 acres and is utilized by chum and coho salmon, along with steelhead and coastal cutthroat trout. No anthropogenic barriers are reported in this stream system. However, Munday (1999) reported that culverts on several tributaries were blockages. However, Washington Trout (In Progress) did not report similar observations.

LAND USE

Land use is a mixture of forest, agriculture and rural residential.

RIPARIAN CONDITION

Riparian habitats vary from older second-growth coniferous and deciduous forests to grasslands where stock grazing occurs and animals have access to the creek. Some logging activity occurs on larger interior parcels that is believed to impact the creek. Of the stream reaches examined by Washington Trout survey crews in 2000, approximately 70 percent were shaded.

SEDIMENT CONDITION

Table Vashon-4 shows substrate types in Shinglemill Creek and selected tributaries

Table Vashon-4. Shinglemill Creek and Selected Stream Substrate Types.

Stream Name	Boulder %	Cobble %	Gravel %	Sand %	Mud %	Bedrock %
Shinglemill Ck.	10	20	30	30	5	5
Needle Ck.	0	20	50	20	5	5
J & Y Creek	0	10	50	30	0	10
Pit Bull Creek	5	10	50	20	10	5
Unnamed trib.	0	20	50	20	5	5

Source: Washington Trout (In Progress).

Table Vashon-5 illustrates approximate overall pool-to-riffle ratios within the Shinglemill Creek subbasin.

Table Vashon-5. Pool-to-Riffle Ratios in Shinglemill Creek Subbasin.

Stream Name	Pool-to-Riffle Ratio
Shinglemill Creek	50:50
Needle Creek	30:70
J & Y Creek	40:60
Pit Bull Creek	30:70
Unnamed trib	30:70

Stream channel bed load and scour was identified as a problem during coho egg incubation periods (Vashon-Maury Island Land Trust 1999). Bed scour of up to 8.75 inches and redeposited sediments of up to 6 inches occurred at some locations in Shinglemill Creek. This data is from only one season sampling effort but is indicative of adverse egg incubation or fry emergent success.

HYDROLOGY

A flow survey was conducted during the 1998/99 winter. Flow discharge rates remained at 5 cfs or less from early August trough mid-November. The highest flows measured were in late November 1998 and January 1999 at 37 cfs and 39 cfs respectively. A more typical seasonal flow during winter months was approximately 10 cfs (Vashon-Maury Island Land Trust 1999).

There are municipal water system wells (Westside Water District) on the mainstem Shinglemill Creek, and historic private water supply systems on Pit Bull Creek and the unnamed tributary.

UNNAMED STREAM (13)

FISH PASSAGE

The creek enters the Puget Sound estuary through a bulkhead that is perched 3 feet above the beach, eliminating access to anadromous salmonids. The creek moves upstream from this point through a culvert approximately 200 feet long underneath two private driveways. Between the two driveways is a perched culvert that is approximately 3-feet high.

LAND USE

Land use within this subbasin is a mixture of forest and rural residential.

RIPARIAN CONDITION

The riparian condition is typically a mix of second-growth deciduous and coniferous forest and rural residential. Coniferous and deciduous trees are sparse in the lower reaches of the stream and abundant in the upper reaches. Instream structure is dominated by brush with logs and rootwads sparse. Approximately 50 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall,, the substrate condition of this unnamed stream was characterized as 50 percent gravel, 30 percent sand, and 20 percent mud. Pool-to-riffle ratios are reported as 20:80.

HYDROLOGY

No information was located that provided any insight into stream flow of this creek.

HYDROMODIFICATION

The lower reaches of the creek are contained within a culvert, and the stream is channelized along an access road for more than of 300 feet. The creek crosses under Cedarhurst Drive through a county culvert.

OBER CREEK (15)

FISH PASSAGE

Ober Creek enters the Puget Sound estuary via a ditched channel. Potential barriers exist at two culverts that are perched (12 and 18 inches) where the creek crosses underneath of Ober Drive. Salmonids have been observed downstream of the lower perched culvert, but no fish have been sighted upstream

LAND USE

Land use within this subbasin is a mixture of forest and rural residential. The mouth of creek is in the vicinity of single-family residences.

RIPARIAN CONDITION

The riparian condition is mix of second-growth deciduous and coniferous forest along with a brush understory. Instream structure is sparse in all aspects. Approximately 40 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate condition of Ober Creek was characterized as 10 percent cobble, 50 percent gravel, 20 percent sand, and 20 percent mud. Pool-to-riffle ratios are reported as 30:70.

HYDROLOGY

No data was located that indicated changes in stream flows.

HYDROMODIFICATION

Hydromodification occurs primarily in the reach from downstream of Ober Road to the point where the stream enters the Puget Sound estuary. Local residents remove stream sediments at approximately 10-year intervals to prevent flooding and septic system damage. Depending on the type of sediment removed, this could represent an adverse impact to spawning gravel quantity and quality as well as increase upstream and downstream scour of spawning areas.

SKEEDER CREEK (16)

FISH PASSAGE

There is a possible barrier to anadromous or resident salmonids where the creek enters the Puget Sound estuary through a perched bulkhead.

LAND USE

Land use within this subbasin is a mixture of forest and rural residential. The mouth of has numerous single-family residences

RIPARIAN CONDITION

The riparian condition is a mix of second-growth deciduous and coniferous forest with an understory of brush. Numerous second-growth cedars are present in the ravine. Instream structure is provided by abundant amounts of logs, rootwads, limbs and brush. Approximately 80 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate condition of Skeeder Creek was characterized as 10 percent boulder, 20 percent cobble, 30 percent gravel, 20 percent sand, 10 percent mud, and 5 percent bedrock. Clay banks and associated seeps on a small tributary stream located in the steep ravine reach provide fine materials to downstream reaches. Pool-to-riffle ratios are reported as 40:60.

HYDROLOGY

No data was located that indicated changes in stream flows. At least two private water supply systems that withdraw water are operating in this system.

HYDROMODIFICATION

No data was located that indicated hydromodification other than the water supply systems noted immediately above.

Cove Creek (17)

FISH PASSAGE

There are no known barriers to anadromous or resident salmonids on the mainstem Cove Creek. A culvert located at the mouth of the creek is not believed to be a barrier. No salmonids were found during the year 2000 survey.

LAND USE

Land use within this subbasin is a mixture of forest, agriculture and rural residential.

RIPARIAN CONDITION

The riparian condition is typically a mix of second-growth deciduous and coniferous forest, agriculture (pasture), public park (Beulah Park), and rural residential. In the lower stream reach (75 feet) in the vicinity of the power transfer station, most of the riparian habitat has been removed. Upstream of that location the stream enters a second-growth deciduous and coniferous forest with Himalayan blackberries adjacent to the stream. Stream channel complexity is provided by abundant amounts of brush, while only moderate amounts of logs, rootwads and tree limbs are present. Approximately 60 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate condition of Cove Creek was characterized as 10 percent cobble, 65 percent gravel, 10 percent sand, and 10 percent mud. A natural waterfall and associated bedrock chute is causing some localized stream erosion problems in the most downstream. Stream channel gradients as high as 30 percent are noted in the steeper reaches. Pool-to-riffle ratios are reported as 1:1.

HYDROLOGY

No data was located that indicated changes in stream flows.

The water in the mainstem Cove Creek between tributaries A and B had a brownish color during the 2000 surveys. The origin of this color was unknown. A satellite sewage treatment plant is scheduled for construction in this reach to address failing septic systems that may be the origin of the water color here.

HYDROMODIFICATION

Hydromodification occurs at points where the creek crosses private and county roads. Old private water supply systems in the upper reaches of the stream appear to be abandoned.

LEO’S CREEK (19)

FISH PASSAGE

A debris jam at the mouth of Leo’s Creek may be a barrier to upstream migration of salmonids. No salmonids were found during surveys conducted in year 2000. Diversion of water by private water supply systems may reduce instream flows and limit natural production of salmonids. On tributary “B,” the stream channel crosses a field with an access road. The culvert under this access road has headcut and undermined the culvert creating a 15-foot drop that would be a barrier to fish migration. Anecdotal information by local long-term residents indicates that salmonids were historically present in this stream.

LAND USE

Land use within this subbasin is a mixture of forest, agriculture and rural residential.

RIPARIAN CONDITION

The riparian condition is typically a mix of second-growth deciduous and coniferous forest, pastureland and rural residential. Instream channel complexity is provided my abundant amounts of brush and tree limbs while moderate amounts of logs and rootwads are present. Approximately 80 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate condition of Leo's Creek is characterized as 20 percent cobble, 40 percent gravel, 20 percent sand, and 20 percent mud. A possible source of bedload is associated with the undercut culvert in tributary B. Pool-to-riffle riffle ratios are reported as 30:70.

HYDROLOGY

No data was located that indicated changes in stream flows. A constructed pond forms the headwaters of tributary B, and there are some constructed ponds in the lower reaches of the mainstem creek.

HYDROMODIFICATION

Hydromodification occurs primarily in the reach from Tahlequah Road downstream to the where the stream enters the Puget Sound estuary. Water withdrawal occurs from the private water supply systems near the stream's headwaters.

ROBINWOOD CREEK (20)

FISH PASSAGE

There are no known barriers to anadromous or resident salmonids on the mainstem Robinwood Creek. Coastal cutthroat trout were observed in this creek.

LAND USE

The principal land use within this subbasin is characterized as rural residential.

RIPARIAN CONDITION

The riparian condition is typically a mix of second-growth coniferous and small deciduous trees. Streamside associated cover is provided by second-growth coniferous and deciduous trees and brush. Instream channel complexity is provided by abundant amounts of log, rootwads, limbs and brush. Approximately 80 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate condition of Robinwood Creek was characterized as 10 percent cobble, 50 percent gravel, 20 percent sand, 15 percent mud, and 5 percent bedrock. Pool-to-riffle ratios are reported as 1:1.

HYDROLOGY

No data was located that indicated changes in stream flows. A county landfill exists in this drainage basin, and there are some water quality monitoring wells associated with this landfill. These wells are located uphill from the tributary B headwater springs.

HYDROMODIFICATION

Hydromodification occurs at locations where the stream crosses private and county roads (i.e., Sunset Beach Drive).

GREEN VALLEY CREEK (21)

FISH PASSAGE

Green Valley Creek drains an area of 762 acres on the western side of Vashon Island. Approximately 150 feet upstream from the mouth of the creek is a 3-foot-high diversion dam associated with a small water wheel. There was no plunge pool on the downstream side of the diversion dam and this is believed to be a complete barrier to salmonid migration. No salmonids were observed during the year 2000 survey.

LAND USE

Land use within this subbasin is a mixture of forest, agriculture and rural residential.

RIPARIAN CONDITION

A cultivated garden and ornamental plantings dominate the lower reach of this stream. The landscaped area extends upstream for at least 1000 feet to an area immediately downstream of the first tributary. At this point the creek enters a steeper portion of the ravine and an area of second-growth coniferous and deciduous trees.

Instream structure is provided by moderate amounts of logs, rootwads, tree limbs and brush. Approximately 60 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate condition of Green Valley Creek was characterized as 10 percent cobble, 40 percent gravel, 30 percent sand, 15 percent mud, and 5 percent bedrock. Pool-to-riffle ratios are reported as 30:70.

HYDROLOGY

Stream base and low flow information is shown in table Vashon-2 previously. No data was located that indicated changes in stream flows. There are historic water diversion and private water supply structures in this system. The private water supply systems do not appear to be in use as of the year 2000 survey by Washington Trout (In Progress).

HYDROMODIFICATION

Lateral channel migration is constricted in the vicinity of the small foot bridges found at several locations. The diversion dam and water wheel identified above as a migration barrier are the only other known hydromodifications in this basin.

CHRISTIANSON (JOD) CREEK (23)

Note: Christianson Creek is also referred to as Jod Creek in some literature sources and by local residents.

FISH PASSAGE

Phil Schneider (WDFW) reported the presence of coastal cutthroat trout in this creek in 1995. A culvert perched approximately 3 feet high at Redding Beach Road is believed to be an impassable barrier to salmonids.

LAND USE

Land use within this subbasin is a mixture of forest, agriculture and rural residential. There is a single-family residence at the mouth of the creek.

RIPARIAN CONDITION

The lower stream reaches riparian habitat consists of ornamental plantings and landscaping associated with the residence there. Large boulders have been placed in the stream apparently in an effort to control bank erosion. Upstream of this reach, the riparian condition is typically a mix of second-growth deciduous and coniferous trees and rural residential. Stream channel complexity is provided by abundant amounts of brush and moderate amounts of logs, rootwads and tree limbs. Approximately 70 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate condition of Christianson Creek was characterized as 5 percent boulder, 15 percent cobble, 30 percent gravel, 30 percent sand, 15 percent mud, and 5 percent bedrock. A landslide approximately 600 feet downstream of Redding Beach Road is depositing a moderate amount of sediments into the creek.

There is an active landslide present in the mainstem Christianson Creek near the confluence with tributary “D” that contributes sediments to downstream reaches. This slide appears to be caused by stormwater discharge from a culvert that carries runoff from Redding Beach Road.

Pool-to-riffle ratios are reported as 1:1.

HYDROLOGY

No data was located that indicated changes in stream flows. There are at least two private water collection systems in this subbasin. The Christianson Creek Pond and the two ponds (approximately half an acre each) are constructed ponds and also alter stream flow characteristics.

HYDROMODIFICATION

As noted above there are at least three constructed ponds in this stream system.

UNNAMED STREAM (24)

FISH PASSAGE

No salmonids have been identified in this creek and there is no direct access to saltwater. A culvert at the mouth of the creek is buried and full of sediment. A hand-dug channel diverts the stream into a wetland immediately upstream of the creek mouth, and inflowing surface water exits the wetland subsurface.

There also is a 4-foot perched culvert upstream of the junction of Cross Landing and Redding roads that would be a barrier if fish were present.

LAND USE

Deciduous and coniferous forests dominate land use within this subbasin.

RIPARIAN CONDITION

The riparian condition is typically a mix of second-growth deciduous and coniferous trees. Instream complexity is provided by moderate amounts of logs, tree limbs and brush, while rootwads are sparse. Approximately 90 percent of the stream exists in a shaded condition.

Riprap has been placed into the creek at two locations in an apparent effort to stabilize the streambank along a road.

SEDIMENT CONDITION

Overall, the substrate condition of this unnamed stream (#24) was characterized as 10 percent boulder, 45 percent gravel, 30 percent sand, and 15 percent mud. Pool-to-riffle ratios are reported as 20:80.

HYDROLOGY

No data was located that indicated changes instream flows. As noted above, the creek enters the Puget Sound estuary through porous soils at the mouth after being diverted via a hand-dug channel into a wetland.

HYDROMODIFICATION

Local road crossings and associated culverts effectively limit lateral channel migration in the vicinity of the Cross Landing and Redding roads.

UNNAMED STREAM (26)

FISH PASSAGE

There are no known barriers to anadromous or resident salmonids on the mainstem Unnamed Stream (26). A possible barrier exists at the mouth of the creek where it enters the Puget Sound estuary through a bulkhead. No salmonids were observed in this creek during the year 2000 survey.

LAND USE

Land use within this subbasin is a mixture of forest and rural residential.

RIPARIAN CONDITION

The riparian condition is typically a mix of second-growth deciduous and coniferous forest and rural residential. Approximately 90 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall,, the substrate condition of unnamed Stream (#26) is characterized as 60 percent gravel and 40 percent sand. Pool-to-riffle ratios are reported as unknown.

HYDROLOGY

No data was located that indicated changes in stream flows. Anecdotal information indicates that this stream occasionally goes subsurface and/or dry during late summer.

HYDROMODIFICATION

There is no known hydromodification in this stream.

UNNAMED TRIBUTARIES (27, 28 AND 29)

These streams are grouped together because of their similar characteristics and geographic location.

FISH PASSAGE

All three streams enter the Puget Sound estuary via restrictive bulkheads along the shoreline. These bulkheads effectively restrict access from saltwater for anadromous salmonids.

LAND USE

Land use within this subbasin is a mixture of forest and rural residential. The mouth of each creek has single-family residences nearby.

RIPARIAN CONDITION

The riparian condition is typically a mix of second-growth deciduous and coniferous forest and rural residential. Approximately 60 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate condition of these streams was characterized as 70 percent gravel and 30 percent. Pool-to-riffle ratios are reported as 10:90.

HYDROLOGY

No data was located that indicated changes in stream flows.

HYDROMODIFICATION

No data was located that indicated any hydromodification in these streams.

BATES CREEK (30) (H2)

FISH PASSAGE

There are three private driveway culverts approximately 100 feet upstream of the mouth of the creek that are probable barriers to anadromous fish migration. Cutthroat fingerlings have been observed downstream of these culverts but none were observed upstream.

LAND USE

Land use within this subbasin is a mixture of forest and rural residential

RIPARIAN CONDITION

The riparian condition is typically a mix of second-growth deciduous and coniferous forest and rural residential. Instream structure and complexity is provided by moderate amounts of brush, logs, rootwads and tree limbs.

SEDIMENT CONDITION

Overall, the substrate condition of Bates Creek was characterized as 60 percent gravel, 25 percent sand, and 15 percent mud. Pool-to-riffle ratios are reported as unknown.

HYDROLOGY

No data was located that indicated changes in stream flows.

HYDROMODIFICATION

No data was located that indicated the presence of hydromodifications in this stream.

SEALTH CREEK (32)

FISH PASSAGE

The mouth of Sealth Creek enters the Puget Sound estuary via a bulkhead and is contained within a culvert to a point approximately 200 feet upstream. The bulkhead and associated culvert are barriers and eliminate any marine access to the upper reaches of Sealth Creek by anadromous salmonids.

LAND USE

Land use within this subbasin is a mixture of forest and rural residential. The mouth of the creek is through Girl Scout camp (Camp Sealth).

RIPARIAN CONDITION

The riparian condition is a mix of second-growth deciduous and coniferous forest and in the lower reaches is criss-crossed with trails. Stream channel complexity is provided by moderate amounts of brush and tree limbs while there are sparse amounts of logs. No rootwads were present during the year 2000 survey. Approximately 90 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate condition of Sealth Creek was characterized as 20 percent gravel, 70 percent sand, and 10 percent mud. Pool-to-riffle ratios are reported as 10:90.

HYDROLOGY

No data was located that indicated changes in stream flows.

HYDROMODIFICATION

Hydromodification occurs primarily in the reach associated with Camp Sealth.

S-1 AND S-2 CREEKS (33 AND 35)

These creeks are north and south respectively of Spring Beach Creek and are grouped together here because of similar characteristics and geographic location.

FISH PASSAGE

A sand bar and debris jam at the mouth of S-1 and S-2 eliminates access from marine waters. No salmonids were observed in either creek.

LAND USE

Land use within these creeks is dominated by deciduous and coniferous forests. A boat in only campsite is associated with the mouth of S-2.

RIPARIAN CONDITION

Both creeks originate in the steep ravines of the eastern Vashon Island shore. The riparian condition is typically a mix of second-growth deciduous and coniferous forest. Alder with invasive ivy dominates the riparian corridor of S-2.

Instream complexity is dominated by tree limbs and brush with logs and rootwads being sparse or absent. Approximately 100 percent of S-1 and 90 percent of S-2 exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate type of S-1 was characterized as 25 percent gravel, 50 percent sand and 20 percent mud. Substrate type for S-2 was 10 percent gravel, 70 percent sand, and 20 percent mud.

HYDROLOGY

No data was located that indicated changes in stream flows.

HYDROMODIFICATION

No information was located that showed any hydromodification in either stream.

SPRING BEACH CREEK (34)

FISH PASSAGE

No salmonids were observed in this creek during the 2000 surveys. The creek flows into the Puget Sound estuary through a perched bulkhead and then travels upstream for approximately 60 feet through a culvert under Spring Beach Creek Road. These are both impassable barriers to anadromous salmonids.

LAND USE

Land use within this subbasin is a mixture of forest and rural residential.

RIPARIAN CONDITION

The creek flows through the group of houses sometimes referred to as Spring Beach. Riparian conditions are a mix of second-growth deciduous and coniferous forest along with ornamental plantings. Instream complexity is provided by moderate amounts of tree limbs and brush, while logs and rootwads are sparse. Approximately 70 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate condition of Spring Beach Creek was characterized as 35 percent gravel, 40 percent sand, and 25 percent mud.

HYDROLOGY

Stream base and low flow information is shown in table Vashon-2 previously. No data was located that indicated changes in stream flows.

HYDROMODIFICATION

A community water system tank approximately 400 feet upstream of the creek's mouth removes water from the creek. Hydromodification also occurs in the reach upstream of the culvert for approximately 350 feet where the creek is confined to a ditch. Upstream of the community water tank, the stream reverts back to a more natural state.

SLAIGHTERS CREEK (36)

FISH PASSAGE

No salmonids were observed in this creek during year 2000 surveys. Impassable barriers are present from the mouth upstream through a culvert to a series of small ponds and at a three-way standpipe in the vicinity of Pohl Road.

LAND USE

Land use within this subbasin is primarily residential. The mouth of the creek has numerous single-family residences.

RIPARIAN CONDITION

The riparian condition is in the lower reaches is inside a natural ravine that with brush and smaller deciduous trees. After moving upstream out of the ravine the creek channel traverses through residential landscaped lots. At Pohl Road, a three-way standpipe brings the three streams and two seeps together. The mainstream channel upstream of this point again traverses through residential landscaped lots before entering a small ravine with similar riparian vegetation to the lower ravine. The percentage of stream shaded is approximately 50 percent.

SEDIMENT CONDITION

Overall, the substrate condition of Slaighters Creek is characterized as 75 percent gravel, 15 percent sand, and 10 percent mud. The pool-to-riffle ratio is reported as 10:90.

HYDROLOGY

No data was located that indicated changes in stream flows.

HYDROMODIFICATION

Hydromodification occurs throughout in the reaches in the residential areas of Slaighters Creek and Pohl Road.

TAHLEQUAH CREEK (37)

Tahlequah Creek runs from north to south, has a drainage basin of 780 acres, and empties into the Puget Sound estuary at the southern tip of Vashon Island.

FISH PASSAGE

There are no known barriers to anadromous or resident salmonids on the mainstem Tahlequah Creek. A possible barrier exists on the second left bank tributary (B) where it exits a constructed pond (~3/4 acre) via a stand pipe. Coastal cutthroat were observed in this creek and chum utilization is suspected (Williams 1975).

LAND USE

Land use within this subbasin is a mixture of forest and rural residential. The mouth of has numerous single-family residences

RIPARIAN CONDITION

The riparian condition is typically a mix of second-growth deciduous and coniferous forest and rural residential. Stream channel complexity is provided by abundant amounts of brush, moderate amounts of logs and tree limbs and sparse numbers of root wads. Approximately 90 percent of the stream exists in a shaded condition.

After the mainstem creek emerges from the forest upstream of Tahlequah Road, it passes under the road via a large culvert and into a narrow cement trough where it is channelized past several private residences. After passing though a series of small stair-steps and across a rough cement slab the creek enters the Puget Sound estuary.

SEDIMENT CONDITION

Overall, the substrate condition of Tahlequah Creek was characterized as 60 percent gravel, 35 percent sand, and 5 percent concrete. The percentage of the stream channel in pools is approximately 10 percent.

HYDROLOGY

Stream base and low flow information is shown in table Vashon-2 previously. No data was located that indicated changes in stream flows.

HYDROMODIFICATION

Hydromodification occurs primarily in the reach from Tahlequah Road downstream to the where the stream enters the Puget Sound estuary.

SHAWNEE CREEK (40)

FISH PASSAGE

The mouth of the creek consists of a 4-foot-high perched bulkhead upstream of which the stream is channelized through a flume prior to being channelized though landscaped private property. Upstream of the first residence, the stream is contained in 150 feet of a 30-inch PVC culvert that goes underneath a private residence prior to being daylighted for 10 feet before entering another culvert underneath Vashon Highway SW. Individually each of these are barriers to anadromous salmonids migration.

LAND USE

Land use within this subbasin is a mixture of residential and forest.

RIPARIAN CONDITION

Upstream of the single-family residences at the mouth of the creek and in its lower reaches, the creek enters an area of second-growth mixed deciduous and coniferous trees.

SEDIMENT CONDITION

No data was located that indicated overall sediment conditions for Shawnee Creek. Suitable spawning gravels are present in reaches upstream of the piped and channelized reaches.

HYDROLOGY

No data was located that indicated changes in stream flows.

HYDROMODIFICATION

Extensive piping and channelization of the lower stream reaches has eliminated any natural stream channel migration.

FISHER CREEK (41)

The Fisher Creek subbasin drains an area of approximately 1,549 acres. The headwaters are north of Old Mill Road and it flows south until it empties into Quartermaster Harbor along the west shore near the mouth of the harbor. Cutthroat trout, coho salmon and sculpin can be found in its lower reaches.

FISH PASSAGE

There is a potential barrier at 232nd Street. WDNR has listed the stream upstream of 232nd Street as a Type 3 to the headwater pond approximately ¼ mile upstream of the road crossing. The outlet structure of the headwater pond is a stand-pipe that controls water elevation and is also a possible barrier to upstream migration.

LAND USE

Land use within this subbasin is a mixture of forest, agriculture and rural residential.

RIPARIAN CONDITION

Where Fisher Creek leaves saltwater it traverses through a channelized and landscaped reach and then crosses under Vashon Highway SW through a 30-inch culvert. Upstream of the highway the creek traverses through an abandoned blueberry patch before entering a steep walled ravine. This vegetation in this ravine is a mixed coniferous and deciduous second-growth forest with a shrub understory of salmonberry, skunk cabbage, and sword ferns. Only limited information was available that indicated the riparian habitat after the creek exited the ravine. Livestock rearing occurs in the upper reaches and the headwater pond is a created structure. Approximately 70 percent of the stream is in shaded reaches.

SEDIMENT CONDITION

Overall,, the substrate is condition is approximately 5 percent boulders, 15 percent cobble, 30 percent gravel, 30 percent sands, 10 percent mud, and 10 percent bedrock. The creek has an approximate pool-to-riffle ratio of 40:60.

HYDROLOGY

The Burton Water Company has facilities located on this creek and withdraws water for domestic use. As is the case with most water withdrawal situations, the greatest need for potable water is during low baseflow periods.

HYDROMODIFICATION

The stream channel has been modified in several places as noted previously in the riparian section above.

JUDD CREEK (42)

Judd Creek was not surveyed by Washington Trout as a part of their year 2000 efforts. It is anticipated that a survey will occur during 2001.

Chum, coho, and chinook salmon (WDFW Spawning Ground Survey Database) along with steelhead trout are known to spawn in this stream system. Coastal cutthroat trout juveniles have also been observed in the lower reaches.

Lack of habitat information is a data gap.

TSUGWALLA CREEK (43)

FISH PASSAGE

There are numerous barriers to anadromous or resident salmonids throughout Tsugwalla Creek. At the mouth of the creek is a constructed 8- to 10-foot-high dam with a 16-foot energy dispersion apron and no plunge pool. This dam has no passage facilities and is an effective barrier to all anadromous salmonids.

No salmonids were observed in any stream reaches of Tsugwalla Creek.

LAND USE

Land use within this subbasin is a mixture of forest and agriculture with a few single family residences.

RIPARIAN CONDITION

Upstream of the dam is a 2- to 3-acre impoundment (Pond 1) that is connected by a 50-foot culvert to a second pond that is approximately 1.5 acres in size. An earthen dam separates Pond 2 from Pond 3 (~1.5 acres). Apparently some of the water in Pond 3 is used for irrigation purposes as a pump was present during a site survey on June 1, 2000. Upstream of Pond 3 was an intermittent stream that flows from seeps in a wetland area covered with skunk cabbage.

SEDIMENT CONDITION

The ponds effectively trap fine sediments and any open stream channels are typically dominated by mud.

HYDROLOGY

Hydrology has been extensively modified by the three ponds and water withdrawal.

HYDROMODIFICATION

The three ponds, piping system, dam, and concrete apron are all extensive hydromodifications that eliminate salmonid production.

RAAB’S LAGOON CREEK (44)

Raab’s Lagoon Creek originates from Maury Island and flows southerly into Quartermaster Harbor.

FISH PASSAGE

There are no known barriers to anadromous or resident salmonids on Rabb’s Lagoon Creek. There is some type of water control structure at the bulkhead at the downstream end of the creek and the exact purpose of this structure is unknown.

LAND USE

Land use within this subbasin is a predominantly agriculture with some single-family rural residences.

RIPARIAN CONDITION

The riparian condition is typically a mix of second-growth deciduous and coniferous forest and rural residential. A small wetland downstream of Dockton Road is fenced to eliminate livestock intrusion. A braided stream channel traverses through a wetland dominated by skunk cabbage and bullrush. Approximately 60 percent of the stream exists in a shaded condition primarily with streamside associated shrubs.

SEDIMENT CONDITION

The creek is a low gradient system and is dominated by mud (60 percent) and sand (20 percent) with patches of 1-6 inch gavels (20 percent). The amount of the stream in pools is approximately 30 percent.

HYDROLOGY

No data was located that indicated changes in stream flows.

HYDROMODIFICATION

Local culverts limit stream channel migration. Upstream of the Dockton Road, the stream channel resembles a roadside ditch as it parallels the road before the creek turns northwesterly where it originates from a series of diverse seeps.

MILETA CREEK (45)

FISH PASSAGE

Mileta Creek has a drainage basin of approximately 700 acres and drains from Vashon Island into Quartermaster Harbor. Coastal cutthroat have been observed downstream of the culvert at Dockton Road. The culvert at Dockton Road is a 3-foot square box culvert with a 5-½-foot vertical drop and represents a barrier to anadromous fish migration. No salmonids were observed upstream of this point. A small tributary (A) that originates from the right bank has a constructed pond at approximately RM 0.05 with a culvert control structure that represents a barrier to anadromous salmonids.

LAND USE

Land use within this subbasin is a mixture of forest, agriculture and rural residential.

RIPARIAN CONDITION

The riparian condition is typically a mix of second-growth deciduous and a few coniferous trees along with some single family residences. Stream channel complexity is provided by logs, rootwads, tree limbs, and brush. A Volkswagen Beetle (VW Bug) was also present in the stream channel about 200 feet upstream of the crossing at Dockton Road. Approximately 80 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate types of Mileta Creek were characterized as 10 percent cobble, 40 percent gravel, 30 percent sand, and 20 percent mud. Overall, 40 percent of the stream channel was in pools.

HYDROLOGY

Stream base and low flow information is shown in table Vashon-2 previously. No data was located that indicated changes in stream flows.

HYDROMODIFICATION

The northern tributary is channelized inside a culvert for approximately 300 feet in the reach where it parallels 240th Street. The box culvert at Dockton Road detailed above in the Fish Access section is also a detrimental hydromodification.

ELLIS CREEK (62)

Ellis Creek is also referred to as Tramp Harbor Creek by some local residents and in some literature.

FISH PASSAGE

Coastal cutthroat trout were observed at numerous points in this stream. At least two barriers to anadromous fish exist in this creek. A culvert perched 2-feet high at SW Ellisport Road and the Water District #19 water storage basins at approximately RM 0.15.

LAND USE

land use within this subbasin is a mixture of forest, agriculture and rural residential.

RIPARIAN CONDITION

The riparian condition is a mix of second-growth deciduous and coniferous forest and rural residential. Larger alders and conifers dominate the riparian zone upstream of the Water District 19 property. However, there was no flow in this reach during a site visit on June 7, 2000. Stream channel complexity is provided by moderate amounts of logs, tree limbs and brush. Rootwads were not observed during the year 2000 survey. Approximately 60 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate type of Ellis Creek was characterized as 30 percent gravel, 30 percent sand, and 40 percent mud.

HYDROLOGY

Stream base and low flow information is shown in table Vashon-2 previously. No data was located that indicated changes in stream flows.

HYDROMODIFICATION

Hydromodification occurs primarily in the reach along Southwest Ellisport Road where the stream channel parallels the roadway, at the Water District #19 instream water storage ponds, which are contained behind dikes and at the road crossings.

ELLISPORT CREEK (63)

FISH PASSAGE

Coastal cutthroat trout are the only salmonid to have been observed in this stream. There are no known barriers to anadromous or resident salmonids on the mainstem Ellisport Creek.

LAND USE

Land use within this subbasin is predominantly of forest. An abandoned oil storage site is located inside the floodplain of the lower reaches of the creek.

RIPARIAN CONDITION

In the lower reaches, the riparian condition is typically a mix of second-growth deciduous and a few coniferous trees. Once the creek enters the ravine the presence of coniferous trees increases but the riparian zone is still dominated by alders and maples. Instream structure and complexity is supplied by logs from deciduous trees, tree limbs and brush. Very few coniferous tree logs are present in this stream channel.

In a lower reach of the stream a power line parallels the stream channel. The trees (primarily alder and maple) in a 200-foot reach have been cut eliminating any functioning riparian habitat in this reach.

A small mass wasting site is present in ravine that is contributing sediments to downstream reaches. This site is approximately 30 feet by 50 feet in size.

Approximately 70 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate types of Ellisport Creek are characterized as 10 percent boulder, 20 percent cobble, 30 percent gravel, and 35 percent sand. The percent of stream in pools was approximately 30 percent.

In the lower reaches of the stream there are numerous old bricks and debris that either originated from the abandoned oil transfer site or greenhouses that were historically in this location.

HYDROLOGY

No data was located that indicated changes in stream flows. Water District #19 does own property on this stream and historically operated a water storage reservoir that is now abandoned.

HYDROMODIFICATION

Hydromodification occurs primarily where the creek is confined by county roads and at culvert crossings. Water District #19 no longer operates the water storage reservoir in this system.

BEALL CREEK (64)

FISH PASSAGE

Beall Creek has a drainage basin of 211 acres along the eastern shore of Vashon Island. Juvenile coastal cutthroat have been observed utilizing this stream. Water District #19 has a pump station on this creek and the diversion dam associated with this facility is a complete barrier to upstream salmonid migration.

LAND USE

Land use within this subbasin is a mixture of forest and rural residential.

RIPARIAN CONDITION

The riparian condition is typically a mix of second-growth deciduous and coniferous forest and rural residential. Brush is abundant throughout the stream. Logs and tree limbs are termed moderate and rootwads sparse.

SEDIMENT CONDITION

No information on the condition of sediments in this stream was located.

HYDROLOGY

No data was located that indicated changes in stream flows. The Water District #19 pump station is a consumptive use of water in this stream. Water is diverted out of the stream for potable water use.

HYDROMODIFICATION

A water diversion dam and associated pump station are the dominate hydromodifications in this subbasin.

GORSUCH CREEK (65)

FISH PASSAGE

Gorsuch Creek drains from the eastern shoreline of Vashon Island. There are several potential barriers to anadromous or resident salmonids on the mainstem Gorsuch Creek, but coastal cutthroat have been observed upstream as far as approximately RM 0.4. These barriers include natural features (e.g., boulder and cobble cascades) and anthropogenic barriers (e.g., an old washed out bridge). A culvert at approximately RM 0.5 that is perched is a barrier to anadromous salmonid migration. The last fish observed during year 2000 surveys was located a about 150 feet downstream of this barrier.

LAND USE

Land use within this subbasin is a mixture of forest and rural residential. are Single-family residences and an old apple orchard are present at the mouth of the creek.

RIPARIAN CONDITION

The riparian condition is dominated by larger second-growth deciduous trees with smaller numbers of coniferous trees. Stream channel complexity is provided by abundant amounts of logs and tree limbs, while rootwads are sparse. Approximately 70 percent of the stream exists in a shaded condition.

At the mouth of the creek is an old apple orchard and grass meadow. Grass and low shrubs cover the stream upstream of the tidewater beach. The creek then enters an area of shrubs composed of salmonberry, sword fern and nettles. The creek then enters riparian zones composed of larger big leaf maple and alder trees with some Douglas fir and small cedars.

SEDIMENT CONDITION

Overall, the substrate condition of Gorsuch Creek was characterized as 20 percent boulder, 20 percent cobble, 20 percent gravel, 20 percent sand, and 20 percent bedrock. In the lower reaches where the stream drops through a ravine, the stream gradient can be quite high (15 percent). In this reach, the substrate is composed of boulders, clay and cobbles with pockets of gravels. Rock impediments are located in several reaches of the stream but do not appear to be barriers coastal cutthroat were observed upstream.

HYDROLOGY

No data was located that indicated changes in stream flows. A sewage treatment plant is in operation in the upper reaches of Gorsuch Creek. Survey crews from Washington Trout

(Washington Trout In Progress) noted on their June 6, 2000 survey that the effluent from the sewage treatment plant was almost the entire streamflows at the facility discharge point and that the water was quite discolored. The channel was dry upstream of sewage treatment plant.

HYDROMODIFICATION

Hydromodification occurs primarily in the vicinity of culverts at road crossings and at the sewage treatment plant.

DILLWORTH CREEK (66)

FISH PASSAGE

A natural barrier to anadromous or resident salmonids is present approximately 800 feet upstream from the mouth of Dillworth Creek. This barrier is a small bedrock waterfall that has headcut into a layer of clay with debris jams immediately downstream. A wooden bulkhead at the mouth of the creek does not appear to be a barrier as of this date.
A culvert at approximately RM 0.4, upstream of Dillworth Road is undermined and is a probable barrier. A natural waterfall (~3 feet high) at approximately RM 0.15 may be a barrier at some flows. The last fish observed during year 2000 surveys was located in the vicinity of the culvert that crosses underneath Dillworth Road.

LAND USE

Land use within this subbasin is a mixture of forest, agriculture and rural residential.

RIPARIAN CONDITION

The riparian condition is dominated by deciduous trees with smaller numbers of coniferous trees. Stream channel complexity is provided by abundant amounts of logs, rootwads, tree limbs and brush. Approximately 70 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate condition of Dillworth Creek was characterized as 25 percent boulder, 35 percent cobble, 15 percent gravel, and 25 percent bedrock. In the lower reaches where the stream gradient is fairly low (~4 percent), there are numerous small debris jams with cobble and boulders. The creek travels through a seam of clay at approximately 800 feet upstream from its mouth. This seam of clay forms the barrier mentioned above. Upstream of these falls the stream gradient increases before flattening out as it exits the ravine.

HYDROLOGY

No data was located that indicated changes in stream flows.

HYDROMODIFICATION

Hydromodification occurs primarily in the vicinity of culverts at road crossings and at an unfinished diversion just upstream of Dillworth Road.

GLEN ACRES CREEK

FISH PASSAGE

Glen Acres Creek drains from the northeastern shoreline of Vashon Island. A bulkhead at the mouth of the creek is perched approximately 4 feet above the beach and represents a complete barrier to anadromous fish access. No salmonids were observed during a June 8, 2000 survey.

LAND USE

Land use within this subbasin is a mixture of forest and rural residential.

RIPARIAN CONDITION

The riparian condition is dominated by deciduous trees with smaller numbers of coniferous trees. Stream channel complexity is provided by moderate amounts of logs, rootwads, tree limbs and brush. Approximately 80 percent of the stream exists in a shaded condition.

SEDIMENT CONDITION

Overall, the substrate condition of Glen Acres Creek was characterized as 10 percent cobble, 40 percent gravel, 30 percent sand, and 20 percent mud.

HYDROLOGY

No data was located that indicated changes in stream flows.

HYDROMODIFICATION

Hydromodification occurs at the mouth of the creek where a bulkhead is present.

LIST OF TABLES

Table Vashon-1: Vashon-Maury Island Streams, Fish Presence, Barriers and Water Withdrawals

Table Vashon-2: Stream Flows of Selected Streams on Vashon-Maury Islands

Table Vashon-3: Streams and Drainage Areas for Water Quality Sampling Stations

Table Vashon-4: Shinglemill Creek and Selected Stream Substrate Types
Table Vashon-5: Pool-to-Riffle Ratios in Shinglemill Creek Subbasin

PART II: FACTORS OF DECLINE/CONDITIONS

4. Summary of Estuary and Nearshore Conditions

4. SUMMARY OF ESTUARY AND NEARSHORE CONDITIONS

INTRODUCTION

The nearshore environment in the WRIA 9 watershed is extremely complex, productive, and provides important habitat structure and functions for the support of salmonids and other fish and wildlife. While historical urbanization and development practices have altered or destroyed much of this habitat, efforts are underway to develop planning and management strategies to reduce ongoing losses and recover habitat processes and ecosystem functions that are vital to the survival of our nearshore natural living resources. Achieving these goals requires an understanding of these processes, functions, and species life history requirements. Unfortunately, while numerous documents describe salmon life history, habitat requirements, and strategies for assessment, recovery, and management, few even mention estuarine and marine ecosystems and life history requirements, even though anadromous salmonids depend heavily upon the nearshore for early survival and spend most of their lives in the marine environment. This lack of scientific knowledge leaves us few alternatives but to develop a conceptual approach to understanding the nearshore ecosystem and how salmonids depend upon and interact with the system.

A conceptual model builds upon existing knowledge of the physical, chemical, and biological processes that form and maintain habitat. In addition, it may use principles of conservation biology and landscape ecology and account for effects of human-induced activities. Conceptual models show how various processes interact to form nearshore habitat and ecological functions important to salmonids. In the absence of adequate levels of quantifiable data, we can use such a model to help us understand how natural processes interact and how alterations or modifications in these processes may affect multiple or individual species. For example, erosion of coastal bluffs that were built from glacial deposits, and the transport of these sediments along the shoreline, are processes that form and maintain our beaches. Rivers and streams also supply sediments to our beaches. Sediment type and distribution determines species composition and use in certain areas. If sediment sources are cut off, or distribution is interrupted, it could change the plant and animal species composition within an area. Indirectly, these changes could affect salmonids if those species happen to be important for refuge or prey items for salmonids. There are numerous examples of how alterations in ecosystem processes, individually and cumulatively, change habitat characteristics and may affect salmonids directly or indirectly. Yet, we know little about many of these individual processes and even less about the ecosystem as a whole.

This chapter begins with a conceptual model of salmonid use of the nearshore, and discusses what is known about salmonid use of the nearshore and the factors that may adversely affect salmonid habitat. Key findings and data gaps are listed at the end of each section. Much of the information in this chapter is drawn from the draft *Reconnaissance-level Assessment of the State of the Nearshore* report (SONR) (Williams, et al. In Prep.). The draft SONR gathers together existing information about selected nearshore and estuarine habitats and species, providing a summary of what is known about the nearshore ecosystem in WRIAs 8 and 9. Because the SONR is still in draft form, all information in this chapter is considered **preliminary and subject to change**. The final report will refine and expand upon the information offered below, and list recommendations for addressing data gaps and habitat limiting factors in the nearshore environment. Readers are strongly encouraged to refer to the final document, which is scheduled for publication in January 2001.

GEOGRAPHIC SCOPE

This chapter covers the marine and estuarine nearshore environments of WRIA 9, including Vashon and Maury Islands (Figure NS-1). This area encompasses approximately 83 miles of shoreline, of which 49 are on Vashon and Maury Islands. The northern boundary of the WRIA 9 nearshore is West Point, and the southern boundary is just north of Dumas Bay in the City of Federal Way. The Washington Department of Ecology places Vashon and Maury Islands within WRIA 15. However, discussions are underway with Kitsap County, Lead Entity for WRIA 15, on an agreement to include Vashon and Maury Islands in WRIA 9 for planning purposes. Therefore, nearshore and estuarine environments of Vashon and Maury Islands are included in this chapter. While the geographic scope of this chapter is WRIAs 8 and 9, it is important to note that salmonids from other WRIAs utilize the WRIA 9 nearshore as they migrate.

DEFINITION OF THE NEARSHORE

The nearshore environment is strongly linked to both upland habitats and deeper waters, and is the interface between marine and terrestrial environments. For the purposes of this report, the seaward boundary of the nearshore is the outer limit of the photic zone [approximately -30 meters Mean Lower Low Water (MLLW)] (Figure NS-2), or the depth beyond which there is insufficient sunlight penetration for active photosynthesis. The nearshore environment extends landward to include coastal landforms such as bluffs, the backshore, sand spits and coastal wetlands, as well as the riparian zone on or adjacent to any of these areas. In addition, the nearshore environment includes sub-estuaries such as the tidally influenced portions of river and stream mouths (Figure NS-3). Examples of sub-estuaries in WRIA 9 include the mouths of direct drainages to Puget Sound such as the Duwamish River and Miller and Des Moines Creeks.

SALMONID USE OF THE NEARSHORE ENVIRONMENT

Salmonids, particularly chinook, chum, and the anadromous form of cutthroat trout, depend upon the nearshore environment both as juveniles and as adults. The nearshore environment is also vital to numerous aspects of the food web upon which all anadromous salmonids depend. This section presents a conceptual model of salmonid use of the nearshore environment and then discusses salmonid use in detail.

CONCEPTUAL MODEL

The nearshore environment is complex and can be highly productive. It is constructed and maintained by a wide variety of processes. Figure NS-4 is a conceptual model illustrating how these processes interact to form nearshore habitat structures, which provide essential ecological functions to salmonids. The figure also shows the locations where human activities affect this ecosystem.

The geoclimatic setting provides many of the building blocks for the ecosystem. For example, the geologic history of Puget Sound left massive deposits of sediments. The bathymetry and topography of Puget Sound create the basis for shallow, deep, and steep habitats. A wide variety of physical, chemical, and biological processes work with these building blocks to create habitat structure. Erosion and sediment transport processes carry sediments to beaches, spits, and other coastal landforms. Tides bring nutrients, and expose certain areas and inundate others. Fresh water flows into Puget Sound via rivers, streams, and seeps, all of which create complex patterns of salinity.

These ecological processes create a diversity of habitat types that provides essential ecological functions. Where and when these processes operate without interruption, they create connected habitats. The quantity and quality of habitat also are linked to these processes; where they operate naturally, they generate high quality habitat. These processes also contribute to the foodweb through nutrient cycling, tidal flux, introduction of organic litter and insects, and maintenance of highly productive habitats such as eelgrass. The cumulative result of these processes working in concert is a complex landscape composed of a variety of habitat types and functions.

This system is extremely important to salmonids, particularly juveniles. Cederholm et al. (2000) found that one of the most important concepts in understanding how juvenile salmonids use nearshore habitat is that they do not necessarily use individual habitats. Instead, they utilize a "landscape mosaic" of habitats due to changes in tides, freshwater runoff, and life history requirements. Many factors, such as predator/prey distributions, tides, river flows, and genetic structure, affect how juveniles move through the nearshore. However, the distribution and connectivity of critical landscape features such as brackish rearing and tidal freshwater areas may be just as important in providing opportunities for juveniles to use preferred habitats (Cederholm et al. 2000).

However, in many instances human activities have disrupted the processes that create and maintain this landscape mosaic, as well as the habitats themselves. Shoreline development, particularly bank hardening, blocks the natural erosion processes that create beaches and shallow-water habitats. Diversion of rivers, such as the Cedar and White from the Green, reduces freshwater flows and freshets important for maintaining salinity gradients and complex flood plains. Dredging and channelization of rivers, such as the Green/Duwamish, eliminates estuary complexes and flood plains. Filling of lowlands creates new land for development, but destroys marshes, flats, swamps, and other shallow habitats. Although many of these changes were made historically, habitat loss and disruption of processes continues in the nearshore. As a result, the landscape mosaic upon which salmonids depend has been and continues to be altered, degraded, and in some areas, destroyed.

The remainder of this chapter provides more detail about salmonid use of the nearshore environment, and the factors that adversely affect the nearshore landscape, likely limiting salmonid production.

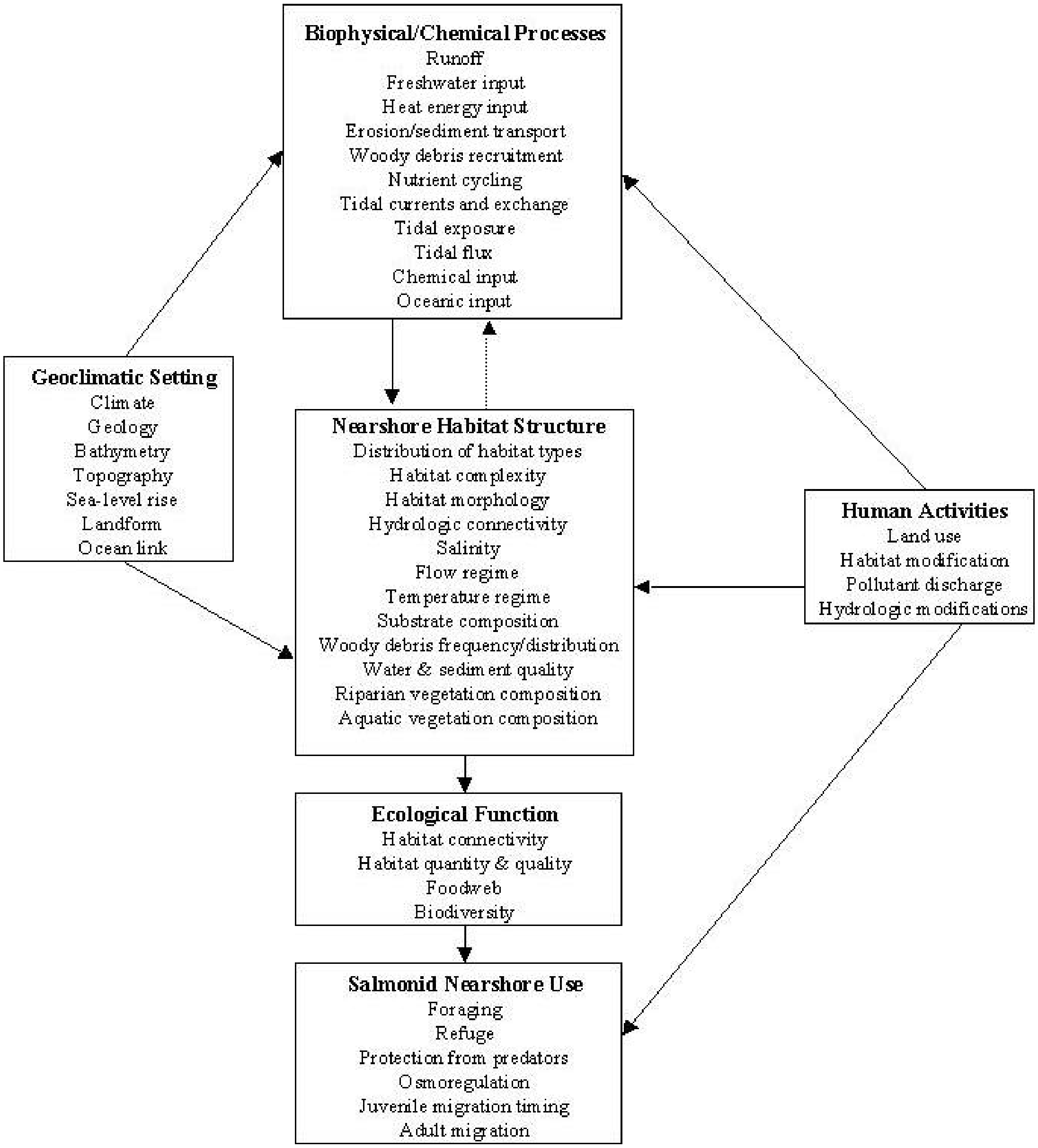


Figure NS-4: Conceptual model of salmonid use of the nearshore environment (after Martin, 1999)

SALMONID USE OF THE NEARSHORE ENVIRONMENT

The landscape mosaic of nearshore habitats provides a number of critical functions for salmonids (Williams and Thom, 2000; Simenstad, 1999; Aitkin, 1998):

- Migratory corridors for both adults and juveniles
- Refuge for both adults and juveniles
- Nursery habitat for juveniles
- Food production and feeding areas for adults and juveniles
- Residence/staging areas for adults
- Physiological transition for adults and juveniles

The following discussion provides an overview of these functions and individual species' use of the nearshore.

NEARSHORE SUPPORT OF JUVENILE SALMONIDS

Studies of juvenile salmonid use of estuaries indicate that early estuarine survival can be a key determinant of adult returns (Simenstad 1999). During this life stage, juvenile salmonids rely on the nearshore for feeding, refuge, and the salinity gradients necessary for the physiological transition from fresh to salt water (Williams and Thom, 2000). Juvenile salmonids depend upon a detritus-based food web for their prey resources. However, the composition of this detritus varies from place to place in the nearshore. Some estuaries depend upon eelgrass more than others, whereas some receive most detritus from rivers, and still others depend more upon phyto-plankton and benthic algae (Wissmar and Simenstad, 1998). Studies to determine the relative inputs of detritus have not been conducted in WRIA 9.

Juvenile salmonids depend upon shallow-water habitats, especially in the early stages as they make the physiologically difficult transition from fresh to salt water, avoid predators, and grow rapidly. In particular, tidal marshes and channels, eelgrass beds, and shallow sand and mud flats provide protection from predators and places to rest and forage. As smolts grow larger and begin to move into deeper waters, they rely more heavily on planktonic prey, but some, especially chinook, continue to eat insects that drift out from shore (Simenstad 1999). Juvenile salmonids rely on high quality and diverse habitats as they migrate to the ocean.

NEARSHORE SUPPORT OF ADULT SALMONIDS

Adult salmonids use the nearshore as a place to feed and rest. Returning spawners may remain in the nearshore environment for up to 21 days before entering freshwater streams and rivers. Throughout the adult phase, several types of forage fish, including surf smelt, sand lance and Pacific herring, are primary prey items for some species of salmonids (Williams and Thom, 2000). These forage fish rely on nearshore habitats for meeting a variety of life history requirements, including spawning, refuge, and feeding. Adult salmonids also use nearshore environments to complete their physiological transition from salt to fresh water.

INDIVIDUAL SPECIES' USE OF THE NEARSHORE

Eight species of anadromous salmonids are present in nearshore areas of WRIA 9: chinook, coho, chum, pink, and sockeye salmon, and steelhead, anadromous coastal cutthroat, and native char. Of all salmonid species, juvenile chinook and chum are the most dependent on the nearshore environment (Williams and Thom, 2000; Aitkin, 1998). Juvenile chinook have been documented as staying up to 189 days in sub-estuarine environments such as marshes and river mouths, but there are no published data that define total residence times in coastal nearshore areas. Most juvenile chinook spend only about two weeks in the heavily industrialized Duwamish estuary (Williams et al., In Prep.). Although the peak juvenile out-migration occurs in spring (March-June), juveniles commonly arrive earlier and may be present in the nearshore environment throughout the year if conditions are favorable. For example, recent beach seining studies found juvenile chinook in WRIA 9 nearshore areas through August (pers. comm., B. Mavros) and into November (pers. comm., T. Nelson). Juvenile chum salmon are also highly dependent on nearshore areas for feeding, refuge, and growth for extended periods (Williams and Thom, 2000).

Juvenile pink salmon feed and take refuge in nearshore environments, peaking from March-June, although they may arrive earlier and stay later. Pink salmon juveniles typically move quickly through sub-estuaries and seem to prefer bays and shallow areas, but may be found in estuarine tidal channels for brief periods. Because coho smolts are much larger than other juveniles by the time they reach the nearshore, scientists believe that they prefer deeper habitats than do other anadromous salmonid species. However, they do utilize shallow-water habitats such as eelgrass and flats in the coastal nearshore and tidal channels in sub-estuaries, as seining studies have shown. Several studies also have shown that juvenile coho utilize sub-estuaries, sometimes in high densities (Johnson, 1999). Juvenile sockeye appear to have the shortest residence time in the nearshore of all salmon species, but take refuge and forage in productive habitats there. Coastal cutthroat trout juveniles, subadults, and adults use a variety of nearshore habitats, but congregate near gravel beaches with upland vegetation and shallow nearshore habitats with large woody debris for feeding and migration. Also, since cutthroat rarely spend the winter in marine waters, they utilize tidal freshwater areas of sub-estuaries until conditions are favorable for upstream migration. Steelhead trout prefer deeper waters and seem to spend very little time in the nearshore. Unfortunately, little is known about native char use of the nearshore environment (Williams and Thom, 2000). However, it is assumed that native char (e.g., bull trout) use the nearshore for feeding and migration. Recent seining efforts have captured native char in the Duwamish River (pers. comm., B. Taylor).

KEY FINDINGS

- Salmonids, especially juveniles, utilize a landscape mosaic, rather than individual habitats *per se* in the nearshore. Eight species of anadromous salmonids utilize nearshore habitats in WRIA 9.
- Salmonids produced in other geographic areas also utilize nearshore habitats in WRIA 9.
- A wide variety of physical, chemical, and biological processes create and maintain the diversity and connectivity of nearshore habitats.
- Human activities can interrupt these processes, and alter, degrade, or destroy habitats.

- Early salmonid survival and growth can be an important determinant of adult returns.
- The nearshore environment provides migratory corridors, nursery areas, feeding and prey production areas, refuge, and habitat for the physiological transition from fresh to salt water environments for juveniles of all species of salmonids.
- The nearshore provides migratory corridors, staging and feeding areas, and habitat for the physiological transition from salt to fresh water environments for adult salmonids.
- All anadromous salmonids utilize and depend upon the nearshore. Of the salmonid species, chinook and chum salmon rely most heavily upon the nearshore environment.

DATA GAPS

- Little detailed information is available on the importance of nearshore habitats to the growth and survival of fish. Actual juvenile salmonid use of eelgrass, kelp, flats, tidal marshes, subestuaries, beaches and backshore areas are data gaps.
- There is a general lack of data quantifying the role of nearshore habitats in the development and survival of juvenile salmonids.
- The relative contributions of different sources of detritus to the food web in WRIA 9 are not known.
- There is limited data on the residence time or migration rates and spatial patterns of juvenile salmonids in the nearshore, or on how these times and patterns influence survival.

NEARSHORE AND ESTUARINE HABITAT LIMITING FACTORS

As discussed in the previous section, salmonids rely upon a complex landscape of habitats in the nearshore environment, but human activities have disrupted this landscape. This section provides more information about these activities and details about their effects in WRIA 9. For the purposes of this report, we have grouped these activities into five categories: (1) loss of habitat in the migratory corridor, (2) degradation of water and sediment quality, (3) alteration of processes, (4) loss of riparian functions, and (5) introduction of non-native species. Each of these is discussed below.

LOSS OF HABITAT IN THE MIGRATORY CORRIDOR

Over the past 150 years, substantial amounts of habitats have been altered and/or destroyed in WRIA 9. By far the most striking example of nearshore habitat loss in WRIA 9 occurred in the Duwamish River Estuary and Elliott Bay, beginning as early as 1895. In order to create new land for development and deeper channels for navigation, 97 percent of shallow areas, flats, and marshes in the Duwamish were eliminated by 1986 (Figure NS-5). All (100 percent) of the tidal swamps bordering the Duwamish were filled by 1940 (Williams et al., In Prep.).

Although these habitat losses may be considered historic, habitat loss continues to occur. Lynn (1998) describes several mechanisms for nearshore habitat loss, including the following:

- Shoreline armoring eliminates riparian habitat, leads to beach erosion, interrupts sediment transport, disrupts organisms dependent on those sediments, and displaces and destroys high intertidal habitat. Vertical bulkheads in lower intertidal zones may slow the migration of juvenile salmonids in migratory corridors (Heiser and Fin, 1970).

- Filling displaces aquatic vegetation, eliminates shallow-water habitats such as marshes and flats, and can cover spawning habitat.
- Dredging kills nearshore organisms during dredging, destroys shallow-water habitats by deepening them, releases toxins into the water column if sediments are contaminated, and removes vegetation that traps sediments.
- In-water structures cast shade, which can kill organisms and seems to prevent juvenile chinook from passing under the structures, interrupting their migration (Williams et al., In Prep.).

Shoreline armoring (i.e., bank hardening) is the placing of structures such as bulkheads, seawalls, and riprap along the shoreline in order to protect upland property from erosion. According to the ShoreZone database recently compiled by the Washington Department of Natural Resources (WDNR), shoreline armoring covers 75% of the shorelines in WRIA 9, and from 50-90% of shorelines in the Duwamish River and Elliott Bay (Williams et al., In Prep.). Therefore, it is reasonable to infer that shoreline armoring has caused a significant amount of nearshore habitat loss and degradation in WRIA 9.

Although the filling of all tidal swamps, and almost all marshes and flats, in the Duwamish River and Elliott Bay are the most dramatic examples of filling in WRIA 9, smaller-scale filling activities continue. Nearshore habitats often are filled to support residential development, especially the installation of shoreline armoring.

Most dredging in WRIA 9 has occurred in the Duwamish River, Elliott Bay, and marinas. Extensive dredging in the Duwamish straightened and widened the channel, eliminated the distributary channels, and created the East and West Waterways. These projects contributed to the near-total loss of flats and marshes in the Duwamish Estuary (Williams et al., In Prep.). Dredging also occurs in marinas and slips in order to maintain navigational safety. In WRIA 9, overwater structures are most prevalent in Elliott Bay and the Duwamish, but residential docks and piers occur along the shorelines of Puget Sound as well (Williams et al., In Prep.).

The combination of these massive, historic habitat losses and the cumulative impacts of smaller, on-going losses has resulted in major changes in the landscape mosaic upon which salmonids depend. However, little is known about the effects of these changes on salmonid use of WRIA 9. Few studies have examined salmonid behavior in developed estuaries versus natural ones, there is no data on possible prey resource limitations in the Duwamish and Elliott Bay, and the effects of shoreline armoring and other development practices on salmonids are poorly understood.

DEGRADATION OF WATER AND SEDIMENT QUALITY

Numerous human activities can lead to degradation of water and sediment quality in the nearshore. Storm water runoff, improperly functioning septic systems, point source discharges, oil spills, agricultural practices, and clearing and grading practices all contribute contaminants to nearshore waters and sediments (Lynn, 1998). Adverse effects of degraded water and sediment quality include smothering of marine plants through excess sedimentation or algal blooms caused by nutrient enrichment (Lynn 1998), and bioaccumulation in fish, shellfish, and mammals (Williams et al., In Prep.).

Water and sediment quality in Elliott Bay and the Duwamish have been degraded severely. Studies have shown that several organic compounds (such as PCBs and PAHs) and metals (such as mercury, cadmium, and zinc) are present in the sediments of some areas of Elliott Bay and the Duwamish at levels that exceed state standards. The most highly contaminated areas are within the East and West Waterways of the Duwamish and west of Harbor Island, and are Superfund sites.

Although there is much less information about water and sediment quality in the nearshore environment of WRIA 9 outside of Elliott Bay and the Duwamish River, the data that exist indicate that water and sediment quality are acceptable. Subtidal water samples indicate that water quality is generally good (http://dnr.metrokc.gov/wlr/waterres/marine/index95.htm) outside of Elliott Bay and the Duwamish. King County monitors sediment quality at Alki Point and Seahurst Park, and has found that the levels of various contaminants in the sediments are well below those thought to be harmful to benthic organisms (Williams et al., In Prep.).

Adverse effects of degraded water and sediment quality include smothering of marine plants through excess sedimentation or algal blooms caused by nutrient enrichment (Lynn 1998), and death of organisms through poisoning or smothering. These processes damage the landscape mosaic upon which salmonids depend, and can decrease their prey resources. Degraded water and sediment quality also can affect juvenile salmonids directly. Several studies have noted that these chemicals bioaccumulate in fish, shellfish, and mammals collected in the Duwamish River estuary, and have found indications of genetic damage in juvenile salmonids (Williams et al., In Prep.). However, not enough is known about the sublethal effects of these contaminants on salmonids or other species.

ALTERATION OF PROCESSES

As the Conceptual Model (Fig. NS-4) shows, many processes create and maintain habitat in Puget Sound, and are fundamental to the maintenance of the habitat mosiac upon which salmonids depend. Human activities have altered or interrupted many of these, but perhaps the most significant changes in WRIA 9 have been interruption of sediment transport and alteration of freshwater input.

INTERRUPTION OF SEDIMENT TRANSPORT

In Puget Sound, nearshore sediments come primarily from slumping of banks and bluffs, while the remainder comes from rivers and streams. The transport of sediments from the landslides and streams is critical to the maintenance of beaches, spits, flats, eelgrass beds, and other nearshore habitats. Waves and currents provide the bulk of this transport, which is organized into units called drift cells. Drift cells are zones along the coast that act as closed or nearly closed systems with respect to transport of sediments (Johannessen, 1992), and generally begin with an area in which sediment is deposited or eroded, such as bluffs (often called feeder bluffs). Waves and currents then carry this sediment to an area of deposition, such as a beach, headland, or spit. Although daily and seasonal changes in tides and currents can change the direction of drift, over the long term each drift cell has a direction of net sediment transport (Johannessen, 1992). Figure NS-6 shows the drift cells in WRIA 9.

In WRIA 9, shoreline armoring and other shoreline development have interrupted the natural movement of sediment. Shoreline armoring traps sediment behind and beneath it, preventing waves and currents from picking it up. Armoring also reflects wave energy more strongly than a natural beach does, causing waves and currents to scour beaches and flats in front of seawalls and other structures, further upsetting the natural balance of sediments. Because shoreline armoring prevents nourishment of beaches while erosion continues to occur, beaches in front of shoreline armoring structures may narrow or disappear entirely (Williams and Thom, 2000).

Other shoreline development can alter sediment transport processes as well. Roads, homes, marinas, and other structures built along the shoreline can deprive the nearshore of sediments. Where structures jut into the water, they can inhibit, and in some instances block, the movement of sediment past them.

The ShoreZone mapping program conducted by the Washington Department of Natural Resources indicates that approximately 75% of the 83 miles of WRIA 9 shoreline is armored. Surveys conducted for the Port of Seattle indicate that nearly 100 percent of the shorelines of the Duwamish River Estuary is modified by dikes, levees, or revetments. From river mile (RM) 12 to the Turning Basin, 56 percent of the shoreline had visible riprap armoring and 3 percent had vertical bulkheads in some portion of the intertidal zone. From the Turning Basin to the mouth of the Duwamish, 65.8 percent of the shoreline is riprapped and 5.3 percent has near-vertical bulkheads. Nearly 90 percent of Elliott Bay is riprapped or armored with rubble, and 16.2 percent has vertical bulkheads or seawalls. Along much of the shoreline, bulkheads or seawalls occur in the upper intertidal zone with riprap or rubble in the lower zone (Williams et al., In Prep.). It is reasonable to infer these extensive modifications of the WRIA 9 shoreline alter natural sediment transport processes.

Sediment transport processes are critical to the formation and maintenance of many nearshore habitats that make up the landscape mosaic. In turn, many nearshore plant and animal species rely on particular sediment sizes for spawning, attachment, burrowing, or root development. For example, forage fish, especially surf smelt and sand lance, require certain sediment grain sizes for their spawning grounds (Williams et al., In Prep.). Forage fish are a key prey item for some species of adult salmonids, particularly chinook and coho. Figure NS-7 shows the known distribution of forage fish spawning beaches in WRIA 9, based upon data from the Washington Department of Fish and Wildlife[1]. Significant changes in sediment size caused by the interruption of sediment transport processes could deprive these important fish of their spawning habitat (Williams and Thom, 2000). Increased erosion also can deprive juvenile salmonids of the shallow habitats they require for protection from predators (Williams and Thom, 2000).

Although shoreline armoring and other development have interrupted sediment transport processes around the Sound, few quantitative studies of the effects of shoreline development on

[1] These data are likely incomplete because surveys have not been conducted on all beaches, or in multiple years. The figure also does not show surveyed beaches where forage fish spawn was not recovered.

sediment transport have been done. In turn, few quantitative studies of the effects of interrupted sediment transport on biological communities exist.

ALTERATION OF FRESHWATER INPUT

Freshwater is very important to nearshore habitats. In particular, in estuaries such as the Duwamish, freshwater is necessary to create the gradations in salinity that influence habitats and species. Floods create complex habitats in natural flood plains. Streams and seeps support riparian vegetation.

In WRIA 9, significant alteration of freshwater input has occurred in the Duwamish River estuary. Historically, the Cedar, Black, Green, and White Rivers flowed into the Duwamish River, producing a mean annual flow of between 2500 and 9000 cfs (Williams et al., In Prep.). The White River was diverted in 1911, followed by the Black and Cedar Rivers in 1916, reducing the drainage area of the Duwamish Basin by 70 percent. Two dams on the Green River, a water diversion dam and the Howard Hansen Dam, further restrict flows and flooding in the system. By 1996, the mean annual flow of the Duwamish was about 1700 cfs, a reduction of between 32 and 81 percent (Williams et al., In Prep.)[2].

These alterations have affected the Duwamish Estuary in a number of ways. The severe reduction in drainage area and management of floods has eliminated the large floods that historically created side channels and sloughs, deposited large woody debris, formed deltas, and reworked sediment deposits. The diversion of the White River removed the historic primary source of sediments for the Duwamish. Reductions in the freshwater input, coupled with dredging of the Duwamish Waterway, allows salt water to penetrate further up the estuary than it did historically (Williams et al., In Prep.). These changes have altered dramatically the landscape upon which salmonids in the Green River depend. However, little is known about how these changes affect salmonid behavior or survival.

LOSS OF RIPARIAN FUNCTIONS

Riparian areas are the transition zones between aquatic habitats and upland areas, such as banks and bluffs. Although much is known about the importance of riparian areas in freshwater systems, relatively little research has been conducted on the functions and values of riparian vegetation in marine systems. Brennan and Culverwell (In Preparation) hypothesize that marine riparian areas provide functions similar to freshwater riparian areas and may provide additional functions unique to marine systems. Marine riparian areas may provide numerous functions including wildlife habitat, erosion control, pollution abatement, sediment retention, shade, organic matter, large woody debris, and salmonid prey items (insects) to the nearshore environment. In particular, data exists to show that salmonids benefit directly or indirectly from many of these riparian functions. For example, juvenile salmonids continue to feed on terrestrial insects even when moving to deeper marine waters (Simenstad 1999), and some species of adult salmonids prey upon surf smelt, which spawn in the upper intertidal zone (Williams et al., In Prep.). Surf smelt eggs, deposited during the summer months, experience higher survival on

[2] For more information about hydrologic modifications in the Green/Duwamish section, see Chapter 2.3, Hydromodification.

shaded beaches than on non-shaded beaches in north Puget Sound, suggesting that the shade provided by riparian vegetation is important to the survival of the species (Penttila, 2000).

However, shoreline armoring and other shoreline development have reduced severely the amount of marine riparian vegetation in WRIA 9. When bulkheads or seawalls are constructed, riparian vegetation is removed. Owners of shoreline residences cut down trees and other native vegetation to improve their views, or make room for structures, roads, and landscaping. The ShoreZone mapping program conducted by the Washington Department of Natural Resources (WDNR) estimated that marine riparian vegetation exists along only 11 percent of the WRIA 9 shoreline. Because WDNR defined marine riparian vegetation as only trees overhanging the intertidal zone, this number likely underestimates the actual amount of marine riparian vegetation in WRIA 9 (Williams et al., In Prep.). However, it is safe to infer that the majority of WRIA 9 shorelines do not have marine riparian corridors that provide effective ecological functions.

NON-NATIVE SPECIES

Non-native species are those species that have been introduced to Puget Sound through a variety of means, including discharges of ballast water from ships, packing materials for seafood shipped from overseas, and intentional or unintentional establishment by the mariculture industry. Non-native species may compete with and/or displace native species, inflicting severe damage on the food web and the nearshore ecosystem.

Very little data exists about non-native species in WRIA 9. The 1998 Puget Sound Expedition identified 39 non-native species in the shallow waters of Puget Sound as a whole (Cohen et al., 1998), but did not indicate which species were found in specific geographic areas. The chapter on non-native species elsewhere in this report contains a comprehensive list of these species.

Non-native species of concern include *Spartina spp.*, salt marsh grasses native to the east coast of the United States that drive out native marsh plants; and *Sargassum muticum*, a seaweed that can smother intertidal species. However, little data exists about these or other organisms' effects on the landscape mosaic upon which salmonids depend, or on salmonids themselves.

KEY FINDINGS

- Massive amounts of habitats critical for juvenile salmonid support in the migratory corridor have been lost. For example, 97 percent of the marshes and flats, and 100 percent of tidal swamps, have been removed from the Duwamish River.
- Shoreline armoring, dredging, filling, and overwater structures have contributed much of this loss of habitat in the migratory corridor.
- Commercial, industrial, and residential development has contributed toxic chemicals and organic compounds to the water and sediments of the nearshore environment in WRIA 9, primarily in Elliott Bay and the Duwamish River.
- Among many others, sediment transport and freshwater input processes are critical for maintenance of important nearshore habitats.
- In WRIA 9, shoreline armoring and development have interrupted sediment processes. Approximately 75 percent of the WRIA 9 shoreline is armored.

- Significant alterations of freshwater input have occurred in WRIA 9, particularly in the Duwamish River basin. These alterations have reduced habitat complexity and sediment loading in the Duwamish.
- Significant amounts of marine riparian vegetation have been lost from WRIA 9 shorelines. The WDNR ShoreZone program estimates that only 11 percent of WRIA 9 shorelines have trees overhanging the intertidal zone.
- Non-native species may be detrimental to salmonid survival in the nearshore in WRIA 9, but more data is necessary to identify specific effects of particular species.

DATA GAPS

- Little is known of the cumulative effects of loss of habitat in the migratory corridor on juvenile salmonids.
- The details of juvenile salmonid use of nearshore habitats are not well understood.
- Complete maps of nearshore habitats do not exist in all areas.
- The carrying capacity of natural and altered nearshore habitat for salmonid support is not fully understood. Similarly, the amount of carrying capacity in the nearshore necessary to support self-sustaining runs of salmonids is not known.
- Sublethal effects of sediment and water contaminants on salmonids and other nearshore organisms are fully understood.
- Very little is known about the cumulative effects of interrupting natural sediment transport processes in the nearshore.
- Although shoreline armoring is very widespread in the nearshore environment, few studies address the effects of armoring on nearshore biota over the long term. Similarly, little is known definitively about the cumulative effects of shoreline armoring on the nearshore environment. More specifically, very few studies have investigated the effects of shoreline armoring on juvenile salmonid feeding, vulnerability to predation, and overall survival.
- Surveys of forage fish spawning areas are incomplete, and stock assessments are absent.
- The effects of the major hydromodification of the Duwamish River on salmonids are not known.
- Very little data on the functions and values of marine riparian vegetation exists.
- Non-native species may be detrimental to salmonid species' survival in WRIA 9, but more data is necessary to identify specific effects of particular species.
- Assessment methods for evaluating habitat quality and for directing mitigation, restoration, preservation, and enhancement efforts are lacking.

REFERENCES CITED

Aitkin, J.K., 1998. The importance of estuarine habitats to anadromous salmonids of the Pacific Northwest: A literature review. U.S. Fish and Wildlife Service, Aquatic Resources Division, in cooperation with the U.S. Fish and Wildlife Service, Puget Sound Program.

Brennan, J.S., and Culverwell, H., in preparation. Marine Riparian: An assessment of riparian functions in marine ecosystems. King County Department of Natural Resources. (Working draft.)

Cederholm, C.J., D.H. Johnson, R.E. Bilby, L.G. Dominguez, A.M. Garrett, W.H. Graeber, E.L. Greda, M.D. Kunze, B.G. Margot, J.F. Palmisano, R.W. Plotnikoff, W.G. Pearcy, C.A. Simenstad, and P.C. Trotter, 2000. Pacific Salmon and Wildlife - Ecological Contexts, Relationships, and Implications for Management. Special Edition Technical Report, Prepared for D.H. Johnson and T.A. O'Neil (Manag. Dirs.), Wildlife-Habitat Relationships in Oregon and Washington. Washington Department of Fish and Wildlife, Olympia.

Cohen, A., et al., 1998. Puget Sound Expedition: A rapid assessment survey of non-indigenous species in the shallow waters of Puget Sound. Prepared for the Washington State Department of Natural Resources, Olympia, WA, and the United States Fish and Wildlife Service, Lacey, WA.

Heiser, D.W. and E.L. Finn, Jr., 1970. Observations of juvenile chum and pink salmon in marina and bulkheaded areas. Washington Department of Fisheries, Management and Research Division.

Johannessen, J., 1992. Net Shore-Drift of San Juan, and parts of Jefferson, Island, and Snohomish Counties, Washington. Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia.

Johnson, R., 1999. Memo: *Miller Creek Estuary Restoration*, King County Department of Natural Resources.

Lynn, B., 1998. Nearshore Habitat Loss in Puget Sound: Recommendations for Improved Management. Washington Nearshore Habitat Loss Workgroup, Puget Sound/Georgia Basin International Task Force.

Martin, D. J., 1999. An Ecosystem Strategy for Restoring Threatened/Endangered Salmon in King County, A Draft Approach.

Mavros, W., 2000. *Personal communication* to Laura Blackmore, King County Department of Natural Resources.

Nelson, T., 2000. *Personal communication* to Laura Blackmore. King County Department of Natural Resources.

Penttila, D.E., 2000. Impacts of overhanging shading vegetation on egg survival for summer-spawning surf smelt, *Hypomesus*, on upper intertidal beaches in northern Puget Sound, WA. Washington Department of Fish and Wildlife, Marine Resources Division, La Connor, Washington, Draft Briefing Report.

Simenstad, C.A., 1999. Commencement Bay Aquatic Ecosystem Assessment: Ecosystem-scale restoration for juvenile salmonid recovery (Final Review Draft). Prepared for the City of Tacoma, Washington Department of Natural Resources, and the U.S. Environmental Protection Agency.

Taylor, W., 2000. *Personal communication* to Laura Blackmore. King County Department of Natural Resources.

Williams, G.D., and Thom, R., 2000. White Paper: Development of Guidelines for Aquatic Habitat Protection and Restoration – Marine and Estuarine Shoreline Modification Issues (Review Draft). Prepared for the Washington State Department of Transportation, the Washington Department of Fish and Wildlife, and the Washington Department of Ecology.

Williams, G.D., et al., In Preparation. The State of the Nearshore Ecosystem: Eastern Shore of Central Puget Sound, Including Vashon and Maury Islands (WRIAs 8 and 9) (Revised Comment Draft). Prepared for the King County Department of Natural Resources.

Wissmar, R.C., and Simenstad, C. A., 1998. Chapter 6: Variability of riverine and estuarine ecosystem productivity for supporting Pacific salmon. *In* Change in Pacific Northwest Coastal Ecosystems. http://www.pncers.org/changeinecosystems.htm.

LIST OF FIGURES

Figure NS-1 Nearshore Bathymetry and Topography, WRIA 9 Nearshore

Figure NS-2 Nearshore Section Illustrating Typical Zonation

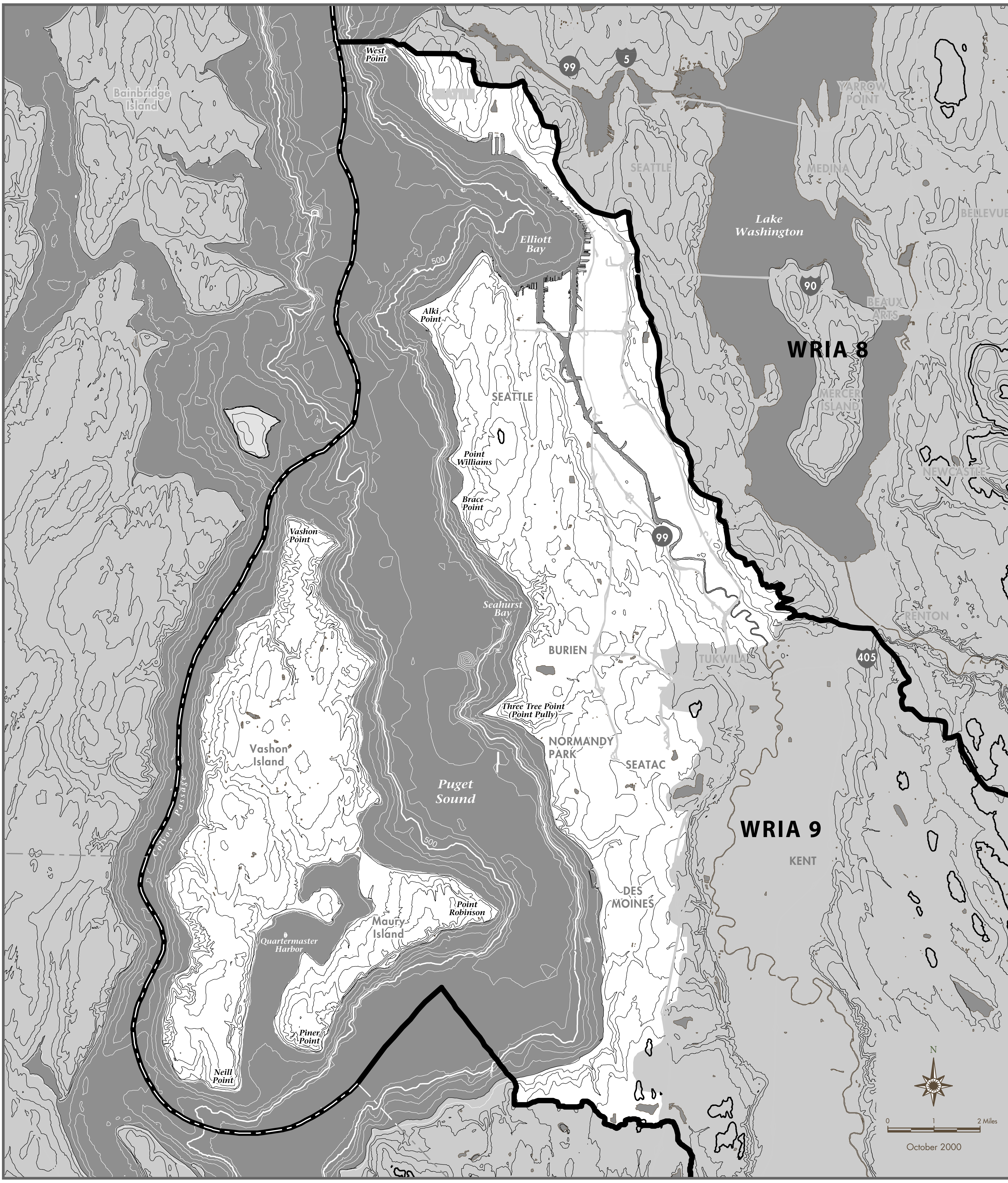
Figure NS-3 Aerial View of Selected Nearshore Habitats

Figure NS-4 Conceptual Model of Salmonid Use of the Nearshore

Figure NS-5 Historic Channel/Shore Locations, Upland Forest and Wetlands, Green-Duwamish River Estuary

Figure NS-6 Drift Cells, WRIA 9 Nearshore

Figure NS-7 Known Forage Fish Spawning Areas, WRIA 9 Nearshore



100 Foot Bathymetric Contour

500 Foot Bathymetric Contour

100 Foot Topographic Contour

500 Foot Topographic Contour

County Boundary

King County WRIA9 Boundary

Nearshore Subbasin Area

Lakes/Major Waterways

Data Sources:
1997 King County/Department of Ecology Hydrography Project, King County political, roads and WRIA boundaries.

King County bathymetry/topography coverage derived from PRISM 10 meter Digital Elevation Model data.

Figure NS-1

Nearshore Bathymetry and Topography

WRIA 9 Nearshore

Poster produced by:
King County DNR
GIS & Visual Communications Unit, WLR
0012 W9 NearBathy.ai LP

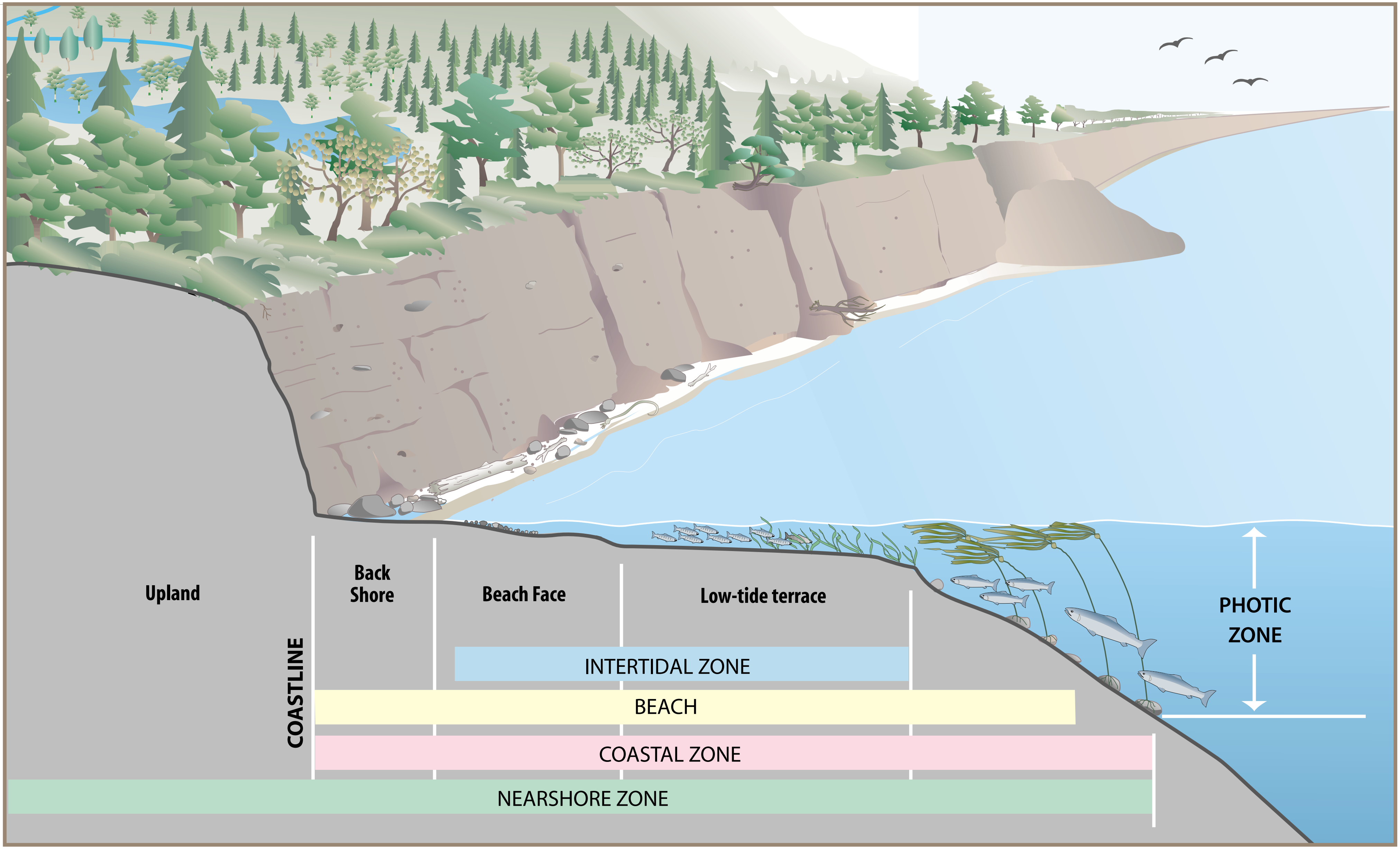


Figure NS-2

Nearshore Section Illustrating Typical Zonation

King County
Department of Natural Resources

Map produced by: GIS & Visual Communications Unit, WLR
File Name: 0012 Near Section.ai

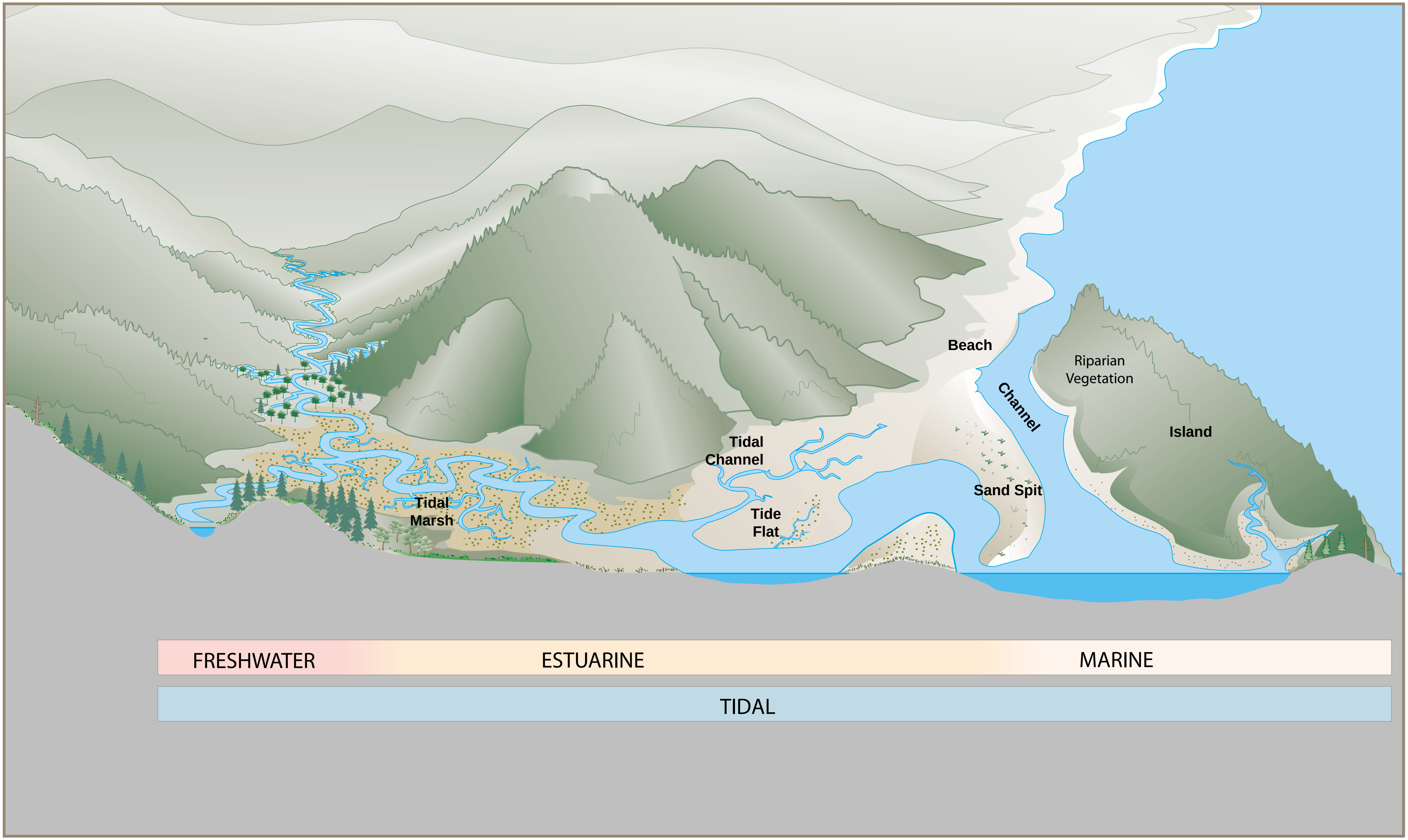


Figure NS-3
Aerial View of Selected Nearshore Habitats

King County
Department of Natural Resources

Map produced by: GIS & Visual Communications Unit, WLR
File Name: 0012 Near Persp.ai

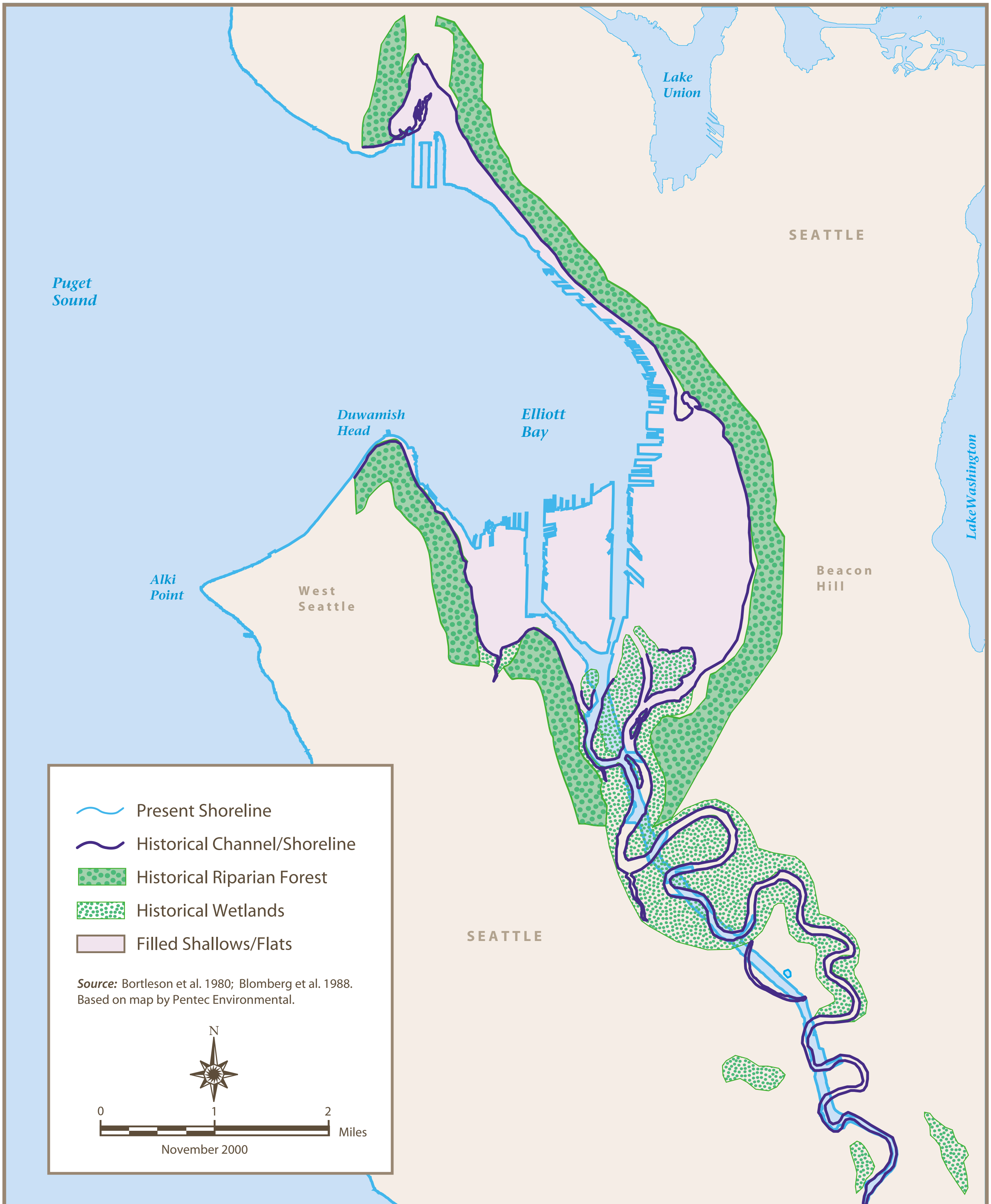


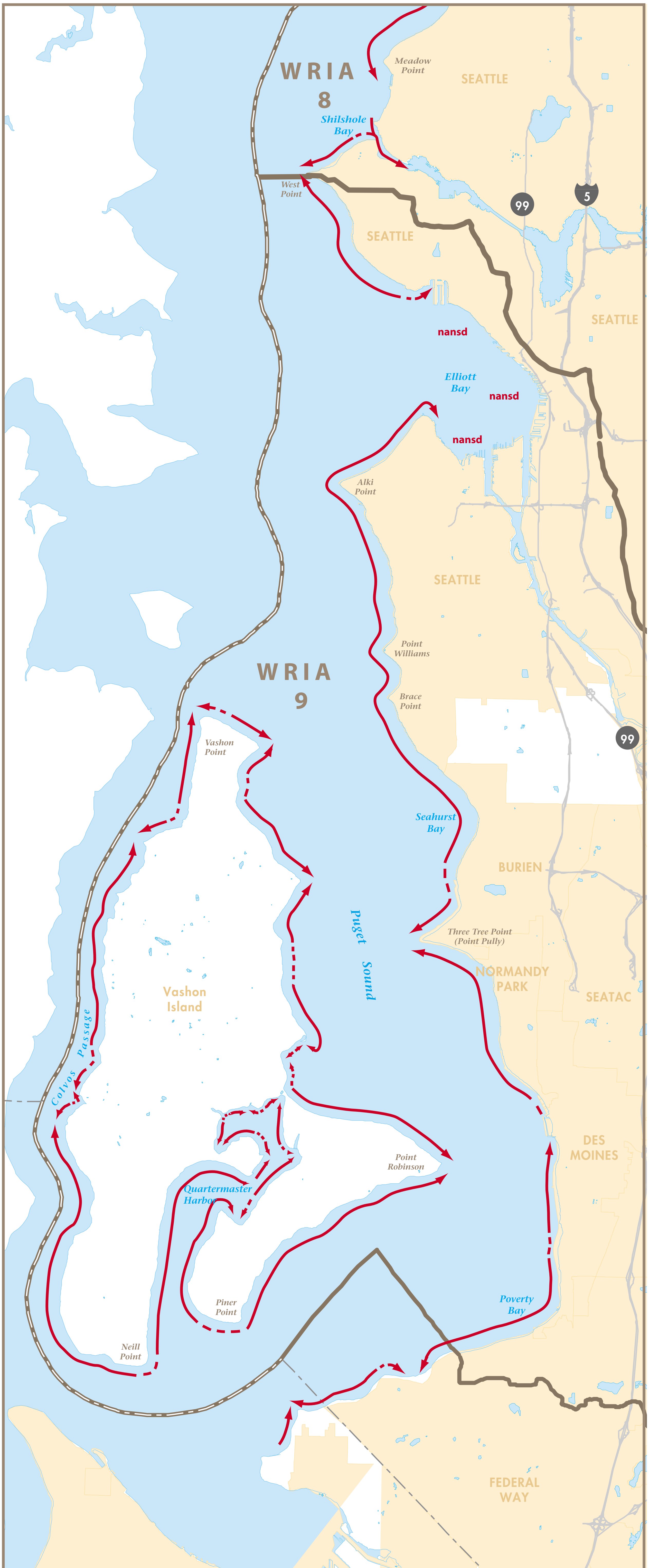
Figure NS-5

Historic Channel/Shore Locations, Upland Forest and Wetlands

Green-Duwamish River Estuary

King County
Department of Natural Resources

Map produced by: GIS & Visual Communications Unit, WLR
File Name: 0011 DuwHist ShoreForWet.ai



nansd No Appreciable Net Shore-drift

Zone of Net Shore-drift Divergence (Erosional zone from which sediment is supplied to diverging drift cells.

Zone of Net Shore-drift (Direction and length)

County Boundary

Highway/Freeway

WRIA Boundary

Lakes/Major Waterways

Incorporated Area

Drift Sector Source:
Chrzastowski, M.J. (1982). *Net Shore-drift of King County, Washington.* Master's thesis, Western Washington University.

Other Data Sources:
1997 King County/Department of Ecology Hydrography Project, King County political, roads and WRIA boundaries.

N

0 1 2 Miles

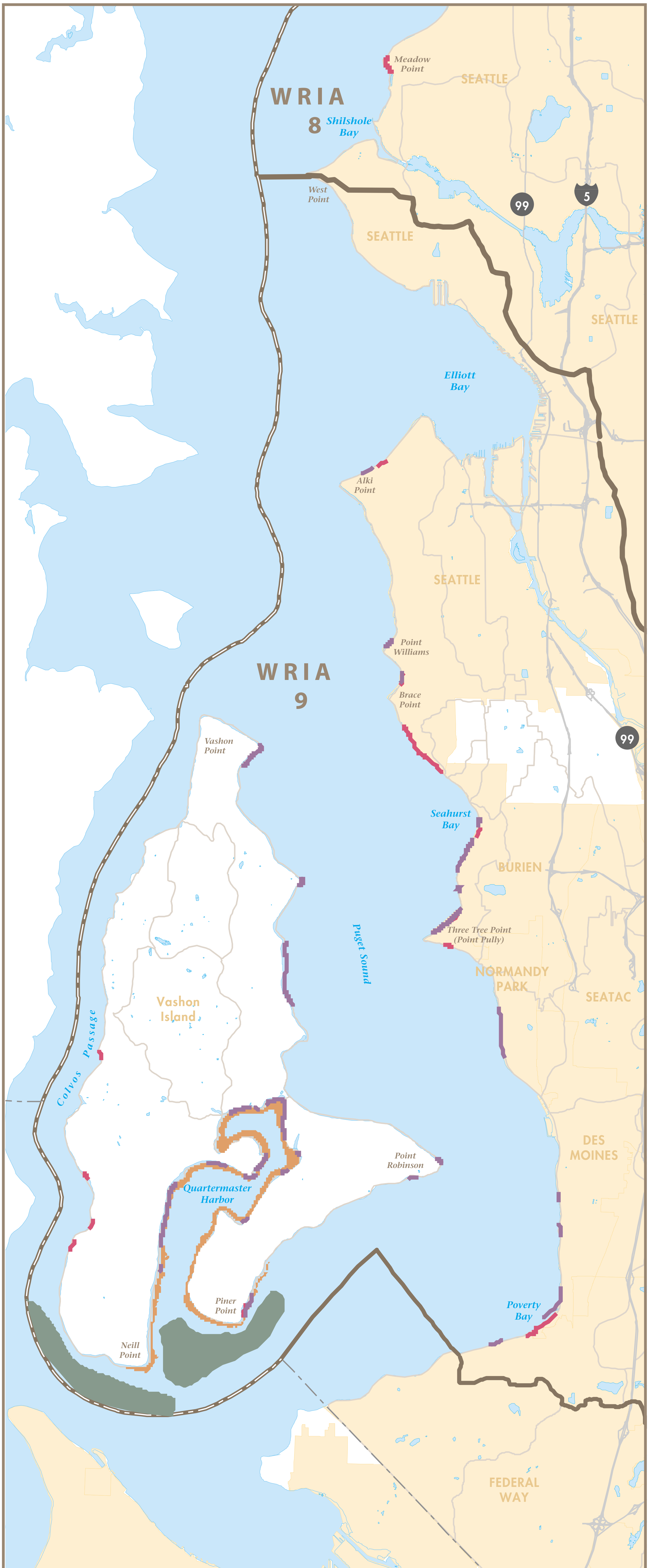
October 2000

Figure NS-6

Drift Cells

WRIA 9 Nearshore

Produced by:
King County DNR
Visual Communication/GIS Unit
0010 Near Drift9.ai lp



Documented Sand Lance Spawning Beaches (10/1999)

Documented Surf Smelt Spawning Beaches (10/1999)

Documented Pre-Spawn Herring Holding Area (1995)

Documented Herring Spawning Grounds (10/1999)

County Boundary

Drainage Basin Boundary

WRIA Boundary

Lakes/Major Waterways

Incorporated Area

Notes:

1) Surf smelt data are offset slightly into the Sound for clarity purposes.
2) Lack of documentation does not necessarily indicate that any specific site does not have the potential to serve as a spawning site.
3) All users of this map should seek the assistance of qualified professionals and refer to the original data source to ensure that such users possess complete, precise, and up to date information on forage fish spawning distribution and water body location.
4) Please refer to the text of this report for further information on the interpretation and use of this graphic.

Data Source:
Washington Department of Fish and Wildlife (WDFW)

N

0 1 2 Miles

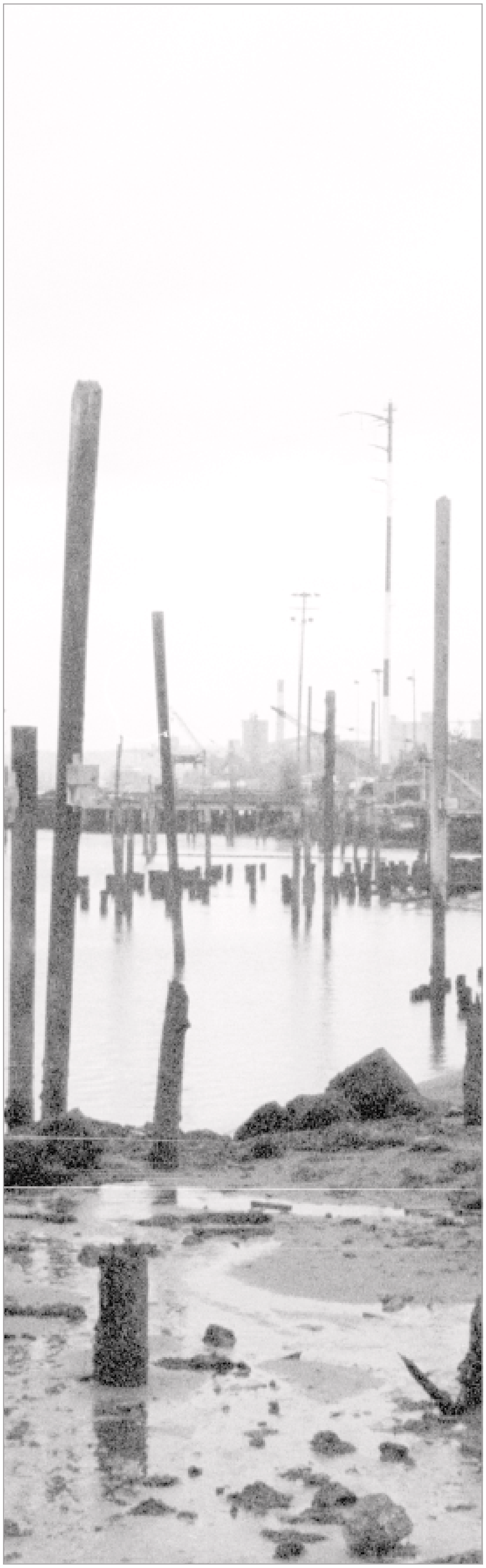
October 2000

Figure NS-7

Known Forage Fish Spawning Areas

WRIA 9 Nearshore

Poster produced by:
King County DNR
Visual Communication/GIS Unit
0010WRIA9NearForageFish.ai lp,sk



PART III
SUMMARY

1. Assessment

2. Conclusions

PART III: SUMMARY

1. Assessment

1. ASSESSMENT

Part III of the Habitat Limiting Factors and Reconnaissance Assessment Report summarizes information presented in the previous limiting factors chapters, and makes some preliminary conclusions based on the information gathered in this report. It is organized in two chapters. Chapter 1: Assessment, includes a description of key findings and data gaps for each of the limiting factors. Chapter 2: Conclusions, includes a description of principles for the watershed, followed by a recommended strategy, and action recommendations to address each of the limiting factors. The key findings and data gaps describe the context and limitations of salmon recovery in WRIA 9. These limitations, combined with the overarching principles for salmon recovery form the basis of the strategy for WRIA 9 recovery. This strategy, in turn, guides the action recommendations.

The following key findings and data gaps are taken from individual chapters in the Habitat Limiting Factors and Reconnaissance Assessment Report.

PART I: CHAPTER 3. CURRENT SALMONID POPULATION CONDITIONS

KEY FINDINGS

GREEN/DUWAMISH WATERSHED-WIDE

- Every species of anadromous salmonids that are native to the North Pacific Region plus one non-native species (Atlantic salmon) have been recently documented to be present in the Green/Duwamish River and tributaries: chinook, coho, chum, sockeye, and pink salmon plus steelhead, coastal cutthroat, and bull trout/Dolly Varden trout.

- The stock status of Green River summer/fall chinook, Crisp Creek fall chum, Green River/Soos Creek coho, and both the summer and winter steelhead stocks are described as healthy by both Washington Department of Fish and Wildlife and the Western Washington Treaty Tribes in their 1994 stock status review. Newaukum Creek coho are described as depressed in that same review. The National Marine Fisheries Service lists the Puget Sound summer/fall chinook Evolutionary Significant Unit (ESU) as Threatened under the Endangered Species Act and the Green River summer/fall chinook stock is a part of that ESU.

- The stock status of Green River fall chum, sockeye, and bull trout is described as unknown.

SUMMER/FALL CHINOOK SALMON

- Escapement for the Green/Duwamish River summer/fall chinook stock from 1986 to 1997 averaged 6,031 and ranged from 2,027 to 10,059.

- Draft run-reconstruction information for the years 1989 – 1997 inclusive indicates approximately 56 percent (range: 25 to 83 percent) of the natural escapement in the main-stem Green River was from hatchery reared and released fish.

- For the same time period, in Newaukum Creek, the origin of adult chinook is approximately 45 percent (range: 15 to 79 percent) of hatchery origin.

- Draft data indicate that the contribution of naturally spawned adults to escapement at the Soos Creek Hatchery is approximately 39 percent (range: 1 to 76 percent).

- The initiation of the "mass marking" of hatchery produced chinook began with brood year 1999. This will provide a tool for fish managers to distinguish all age classes of hatchery produced fish from naturally produced fish on the spawning grounds beginning in 2004. The juvenile chinook are marked by the removal of their adipose fin but are not tagged.

COHO SALMON

- The total natural coho escapement goal for Green River coho stocks is 8,700 fish. That escapement goal has been met only three times in 27 years (1965 to 1992 inclusive) and fluctuates over a wide range.

- Significant differences exist in spawn timing between Newaukum Creek and Green River coho stocks. Coho returning to the Green River typically spawn to mid-November. Newaukum Creek coho may spawn into mid-January.

CHUM SALMON

- Chum salmon returning to the Green River consist of two fall-run stocks: Green River chum and Crisp Creek (also referred to as Keta Creek) chum. The origin of Green River fall-run chum is an East Kitsap/wild remnant mix, while the Keta Creek fall-run stock is of East Kitsap.

PINK SALMON

- Green River pink salmon have been characterized as extinct from this basin. However, pink salmon adults are observed in odd number years during spawning ground surveys in the mainstem Green River and a few tributaries and juvenile pink salmon have been captured in a screw trap on the mainstem Green River.

WINTER STEELHEAD

- The stock status of winter steelhead stocks has been characterized as healthy. An escapement goal was established in 1984/85 of 2,000 fish. Actual escapement of wild fish from run years1976/77 to 1998/99 averaged 1,890 fish. The escapement goal has been met in four of the last five years and water conditions in the other year precluded accurate counts.

SUMMER STEELHEAD

- Green River Basin summer steelhead are the result of non-native (hatchery introduced) origin fish from the North Fork Washougal River (Skamania State Fish Hatchery) summer steelhead stock initially introduced in 1965.

- Escapement goals are not set for this stock.

SOCKEYE

- Sockeye adults and juveniles (Jeanes, 2000) have been documented in the Middle Green River sub-watershed.

ATLANTIC SALMON

- Atlantic salmon adults have been captured by sports fishermen and observed recently in the Green/Duwamish River. These were most likely escapees from commercial net pen operations. There has not been any evidence of successful Atlantic salmon reproduction in the Green/Duwamish River watershed.

NATIVE CHAR (BULL TROUT/DOLLY VARDEN)

- The stock status for bull trout in the basin is unknown.

- One of the first observations of native char in Washington was by Suckey, who first observed native char in the Duwamish River during June 1856. During that same expedition he captured an individual fish approximately 35 miles upstream.

- Investigations have not provided any evidence of bull trout spawning in the Green River watershed.

- Native char have been captured as far as RM 40 in the Green River.

- Native char have not been observed or captured upstream of Howard Hanson Dam as a part of surveys conducted by Plum Creek Timber Company.

- Bull Trout/Dolly Varden have been captured in the lower mainstem Green/Duwamish River on several occasions.

COASTAL CUTTHROAT

- WDFW identifies a distinct stock of coastal cutthroat trout in the Green River watershed.

- NMFS found that the scarcity of information available made risk assessments extremely difficult for coastal cutthroat trout. In their final conclusion they determined that there were two alternative conclusions: “(1) there is not enough evidence to demonstrate that coastal cutthroat trout are *not* at a significant risk of extinction, and (2) there is not enough evidence to demonstrate that coastal cutthroat trout are not at risk.” (Johnson 1999).

DATA GAPS

- The Green River mainstem chinook sampling rate was roughly 4 percent due to difficulties in locating samples in the large river and is probably less reliable. Sampling efforts in the mainstem Green River were increased beginning in 1998 but the data have not yet been analyzed.

- Chum salmon escapement information for the Green River basin is sparse.

- No escapement data for Green/Duwamish River watershed origin winter steelhead stocks is available prior to 1978. Escapement estimates are not available for 1997 due to poor water visibility conditions.

- With the exception of one fish, no meristic sampling was conducted on the char captured in the lower Green River basin so it is unclear if they are bull trout or Dolly Varden.

- Data for trends in coastal cutthroat trout abundance in Green River Basin streams is currently not available.

PART I: CHAPTER 4. GENETICS

KEY FINDINGS

FALL CHINOOK

- The Green River has had a fall chinook hatchery program for the last 95 years.

- Green River fall chinook have played an important part in a number of hatchery programs throughout Puget Sound.

- Green River hatchery and Newaukum Creek wild fall chinook populations are genetically indistinguishable.

- The initiation of the “mass marking” of hatchery produced chinook began with brood year 1999. This will provide a tool for fish managers to distinguish all age classes of hatchery produced fish from naturally produced fish on the spawning grounds beginning in 2004. The chinook are marked through the removal of their adipose fin but are not tagged. This will allow for the monitoring of hatchery strays into the Green River and provide a tool to start monitoring any genetic exchange between naturally and hatchery produced fish.

CHUM SALMON

- The Green River has had a chum hatchery program since 1976.

- Green River chum salmon are geographically isolated from other chum salmon populations in Puget Sound.

- Two chum salmon stocks exist within the Green River watershed.

COHO SALMON

- Green River hatchery and Newaukum Creek coho are genetically similar.

- Green River watershed coho are listed as a Candidate for listing under the Endangered Species Act.

WINTER STEELHEAD

- Green River origin winter steelhead are a part of the larger wild Puget Sound winter-run steelhead stocks.

DATA GAPS

- The exact contribution of hatchery fall chinook to mainstem Green River natural escapement is not yet fully known.

- In the Green River watershed, the ramifications of genetic flow between the hatchery and winter steelhead, wild chinook, coho, and chum populations is unknown.

- The extent of chum salmon straying in the Green River watershed is unknown.

- The contribution of hatchery coho to natural escapement is unknown. The reverse is also true.

- The actual extent of any temporal separation in timing between Green River and Newaukum Creek coho is unclear in terms of defining separate stocks.

- In the Green River watershed, the ramifications of genetic flow between the winter steelhead hatchery and wild populations is unknown. Because of timing differences, the genetic flow between these stocks is believed to be low.

PART II: CHAPTER 1.1 LAND USE

KEY FINDINGS

The following key findings were identified when reviewing land use as a factor of decline for salmonids:

- Effects of land use on habitat range from elimination of habitat to degradation of habitat quality to mitigation for environmental damages under existing regulations.

- Historically, local, state, and federal policies have greatly influenced the amount and type of land use that has occurred in WRIA 9:
  - By the early part of the twentieth century, the region and state planned to develop the Duwamish River and Lower Green into the main industrial area in the county and Puget Sound region
  - For the first 120 years of settlement, economic development was the predominant driver of growth and development
  - For the last 30 years, development has occurred under an increasing number of environmental protection policies and growth management policies
  - Specific actions were taken over many years to enable economic growth and develop natural resource industries
  - Many policies have been established in the last 30 years that require sound planning and development at both the regional and local level
  - Meeting multiple objectives for the Growth Management Act, the Endangered Species Act, and other complex regulations creates a challenging, overlapping framework for regulations and protections

- The seven years from 1910 to 1916 saw the most dramatic hydrologic change. During this time period, 70% of the acreage of the Green/Duwamish Watershed was diverted away from the original Green/Duwamish River and a dam was constructed that blocked fish access to 45% of the remainder.

- Growth management is having a significant influence on directing growth to the Urban Growth Area (UGA) and reducing sprawl. However, as population increases, there is a corresponding increase in the amount of developed land:
  - Growth indicators suggest that the UGA is large enough to accommodate projected growth through 2012
  - Eighty nine percent of the population of WRIA 9 is concentrated in the UGA
  - Thirty percent of WRIA 9's land area is within the UGA

- Most of the urban land uses are located in the western third of the WRIA while the middle and upper portions of the WRIA are primarily rural and natural resource lands:
  - Forestry is the primary designated land use at 99% in the Upper Green River sub-watershed
  - Residential development (50%), forestry (27%) and agriculture (12%) are the primary land uses in the Middle Green River sub-watershed

- Residential development (50%), industrial development (17%), and commercial development (10%) are the primary uses in the Lower Green River sub-watershed
- Industrial development (43%) and residential development (39%) are the primary designated land uses in the Green/Duwamish Estuary Sub-watershed
- Residential development (68%) and industrial development (10%) are the primary designated land use in the Nearshore Sub-watershed
- Residential development at 92% is the primary designated land use in the Vashon-Maury Island Sub-watershed

- Population growth has been a driving factor for the rapid development rates in the watershed:
  - Before 1996, the majority of jurisdictions in WRIA 9 were experiencing a 1% per year or higher population growth rate
  - Population growth has slowed since 1997 to less than 1% per year overall in King County
  - Every 1% increase in population growth corresponds with a 2% or higher increase in developed land

DATA GAPS

Land use information currently available presents certain challenges. The information is not currently organized by watershed boundaries. Although a great deal has been written regarding land use and its effect on salmonids, there has not yet been a close look at local regulations and the subsequent effects on salmonid habitat. Below are the identified land use data gaps:

- Prepare land development and demographic information for King County by boundaries of the Water Resource Inventory Areas, sub-watersheds, and basins.

- Inventory permitting and regulatory processes (SEPA and Shoreline review, permit review, sensitive area review, ordinance and regulatory review) throughout the WRIA. Assess the biological implications of various land use activities, regulations, and policies.

- Inventory impervious surface areas (location and amount), road densities, and forest cover retention at a sub-watershed or smaller scale.

PART II: CHAPTER 1.2 WATER QUALITY

KEY FINDINGS

The following key findings were identified when reviewing water quality as a factor of decline for salmonids:

- Water quality conditions in the Lower Green and Duwamish River have improved from the poor water quality conditions that existed in the 1960s. This is a result of the reduction of municipal and industrial discharges (including higher levels of wastewater treatment and reduction of combined sewer overflows (CSOs)) and the relocation of the south municipal wastewater treatment plant outfall to Puget Sound.

- There has been a trend towards increasing surface water temperatures in most tributaries in the urban and urbanizing areas of the region over the past 20 years, probably attributable to urbanization and development, including increased runoff from impervious surfaces and loss of riparian vegetation.

- Temperatures in the mainstem during the summer have peaked between 23 and 24 ^{o} C at stations in the Lower and Middle Green River in studies involving continuous monitoring probes, based on available data. In some years, this is probably of concern for adult chinook migration up the Green River in August and early September. Water temperatures in some tributaries of the Mill (Hill) and Springbrook subbasins have been historically high and are probably of concern for salmonid rearing. Water temperatures during spawning and rearing are also of concern for several Soos Creek tributaries. There are insufficient data and information on the distribution of bull trout in the watershed to assess to what extent localized temperature conditions are a concern for bull trout.

- Dissolved oxygen (DO) levels are one of the most significant issues for salmonids in the basin. In the mainstem, DO levels in the Duwamish and Lower Green rivers are of concern for salmonid rearing on some occasions. In the mainstem above RM 24 (where most mainstem spawning occurs), DO levels in the Middle Green River are occasionally of concern during incubation. DO for incubation and rearing is a probable factor of decline for salmonids in several tributaries, particularly Springbrook Creek, Mill (Hill) Creek, Soos Creek, and Newaukum Creek. The most severe documented DO problem in the basin is in Mill Creek (just north of SR-18).

- Turbidity and total suspended solids (TSS) are possible factors of decline in terms of water column impacts for the Duwamish River, Lower Green River, Mill Creek, and Springbrook Creek. However, no data were available for the duration of exposure, so it is difficult to determine the extent to which TSS is of concern. TSS may be a concern in terms of sedimentation in some areas, but this was outside the scope of this study, and would be better characterized by analysis of sediment deposition or embededness.

- Based on the King County Streams water quality data evaluated from 1996 to 1999, pH, ammonia, and metals are unlikely to be factors of decline for salmonids at the locations analyzed. Ammonia may be a factor of decline in the Mill Creek basin based on data collected between 1990 and 1991 by King County. Metals (cadmium, chromium, copper, mercury, and zinc) may be of concern in Springbrook Creek based on sampling carried out by Ecology and King County (Metro) between 1984 and 1990 that led to its listing on the 303(d) list. It is possible that there are localized areas near stormwater outfalls to smaller tributaries where metals could also be of concern.

- No data were available to assess to what extent organic chemicals such as pesticides, polycyclic aromatic hydrocarbons (PAHs), and phthalates are a factor of decline for salmonids.

- In the Duwamish Estuary, risks to water column dwelling organisms are minimal. However, there are potential risks to benthic organisms from several chemicals in the sediments, most notably bis(2-ethylhexyl)phthalate, 1,4-dichlorobenzene, mercury, polycyclic aromatic hydrocarbons (PAHs), PCBs, and tributyltin (TBT) (King County, 1999). Risks to the benthic community can potentially translate to risks to salmonids via food-chain transfer (bioaccumulation in prey), reduction in function of immune systems, or from potential toxicity to prey organisms (reduction in available food).

- Biological monitoring of macroinvertebrates in the Soos Creek basin (1995-98) found highly variable conditions. Five of eight stations monitored had benthic index of biotic integrity (B-IBI) scores in the fair range, two were in the poor range and one station was in the very poor range. Seven stations monitored in 1999, located throughout the mainstem of the Green River all had B-IBI scores in the fair range. Mill (Kent) and Meridian Valley creeks had B-IBI scores in the very poor range.

- Although aluminum concentrations often exceed the EPA national criterion throughout the watershed, this does not necessarily indicate aluminum is a factor of decline. Measurements of total aluminum include several forms, such as aluminum that is occluded in minerals, clay and sand or is strongly sorbed to particulate matter, that are not toxic, or are not likely to become toxic under natural conditions (U.S. EPA 1988). Therefore, this criterion may be overprotective when based on the total recoverable method because the digestion procedure dissolves some aluminum that is not toxic and cannot be converted to a toxic form under natural conditions (U.S. EPA 1988).

DATA GAPS

- The spatial availability of water quality data are highly variable across the watershed. There is a paucity of sampling locations for the mainstem of the Green River, with only four sampling stations between the Duwamish River (RM 11) and the Tacoma diversion dam (RM 61). Conversely, some tributaries such as Newaukum and Soos creeks have a dense spatial representation, with 18 and 17 sampling stations, respectively. Such sparse coverage in some subbasins could potentially overlook some areas with impaired water quality in the Green River, and result in greater uncertainty in this assessment.

- There is a lack of continuous temperature data for the mainstem and several tributaries. Continuous data are necessary to determine maximum daily temperatures and the duration of temperature exceedences that have the greatest potential to impact salmonids. For example, temperature conditions in Crisp Creek were determined to be unlikely as a factor of decline based on routine monthly monitoring. However, examination of continuous temperature data indicated somewhat frequent small exceedences of the proposed rearing and spawning standards leading to a possible factor of decline determination.

- Data are lacking for many of the water quality parameters that may adversely affect salmon. Available TSS data do not include any information on the duration of exposure, which is needed to evaluate accurately potential effects on salmonids. In an urban watershed with extensive commercial and industrial development characteristic of the Lower Green River and Duwamish River segments, other parameters that could be of concern include metals, pesticides and herbicides, PAHs, and phthalate esters. There is a shortage of data available for these parameters in the water column. Most of the existing data are for sediments.

- The majority of the ambient metals data in the Green River watershed were collected as part of the stormwater monitoring program; therefore, baseflow metals concentrations are generally unknown. Furthermore, between 1996 and 1999, metals data were available in only seven locations in the watershed. Therefore, the subbasins are not well characterized for metals with the current data.

- There is insufficient information on the combined effects of toxicants, such as metals or organic chemicals, on salmonids. Additivity is the characteristic property of a mixture of toxicants that exhibits a total toxic effect equal to the arithmetic sum of the effects of the individual toxicants (U.S. EPA 1991). Synergism is the characteristic property of a mixture of toxicants that exhibits a greater-than-additive total toxic effect (U.S. EPA 1991).

- Unlike chemical data that yield a snapshot of aquatic conditions at the time of sampling, aquatic insects provide an integrated view of overall water quality conditions at a given location. Unfortunately, the only available aquatic insect data (as measured by B-IBI) in the Green River basin was for the Soos Creek subbasin from 1995, 1997, and 1998, and from selected stations on the Green and two tributaries in 1999. Thus, this is a data gap for the basin as a whole.

- There is a need to define closer links between water quality data and site conditions with the historic, current, and potential future distribution of salmonids. It is likely that water quality conditions limited salmonid distribution in the past, even without extensive human activities. For instance, DO and temperature conditions in areas with extensive open water wetlands may not be compatible with fish presence. Also, the DO and temperature requirements for salmonid migration, rearing, and spawning/incubation vary considerably.

- There is an interest in having reference sites based on different geomorphic systems to define background water quality conditions. Without reference sites, it is difficult to define the relative contribution of anthropogenic activities to degraded water quality conditions.

PART II: CHAPTER 2.1 HYDROLOGY

KEY FINDINGS

The following key findings were identified when reviewing hydrology as a factor of decline for salmonids:

UPPER GREEN RIVER

Upstream migration

- The Howard Hanson and Tacoma dams that alter the mainstem hydrology also are blocking the upstream migration of anadromous salmonids. See Passage Chapter of this report for details.

Spawning and Incubation

- One model suggests that timber harvest related disturbances are extensive enough to cause peak flow increases capable of modifying channel conditions (USFS 1996) and mainstem reaches just upstream of the Lester Watershed Administrative Unit (WAU) have recently experienced scour to a depth sufficient to cause redd mortality during high flows (Plum Creek 1996).

- The inundation of up to 7.7 miles of mainstem and tributary habitat will result in lower water velocities, decreased oxygen levels, and increased sediment loads in the redd environment, which can result in embryo and larval mortality. The associated decrease in temperature with the increase in water depth can result in a delay of egg maturation.

- The dams have resulted in the inaccessibility of over 100 miles of combined mainstem, tributary, and side channel spawning habitat to anadromous salmon.

Juvenile Rearing

- The construction of HHD has resulted in a net loss of 7.7 miles of mainstem and tributary rearing habitat (side channel habitat undetermined) due to inundation when operated at full pool. This area has been converted into rearing habitat that fluctuates unnaturally from a lake to free flowing depending on flood control responsibilities.

Downstream Migration

- Downstream migrating salmonid smolts, especially chinook, are delayed within the reservoir behind HHD and subject to increased mortality in the reservoir and through the dam bypass pipe and gates.

MIDDLE GREEN RIVER

Upstream Migration

- Since 1913 the Tacoma water withdrawals at the headworks have severely lowered the natural summer low flows in the mainstem. Howard Hanson dam summer low flow augmentation (since 1962) has helped to increased these flows but not to natural, pre-diversion levels. These low flows in the late summer have only met instream flow requirements in 9 out of the last 30 years (30%) and delay upstream migration of adult chinook salmon. Tacoma's First Diversion Water Right Claim (FDWRC) of 113 cfs is not constrained by these minimum instream flow requirements.

- The lack of freshets, especially during the spring reservoir refill period, may delay salmon (e.g., steelhead) upstream migration.

- Late summer low flows and associated shallow water over many riffles increase the energy expenditure of upstream migrating adult chinook.

- Summer low flows increase the difficulty adult chinook have in moving from the Green River into major spawning tributaries such as Newaukum Creek.

Spawning and Incubation

- Alterations in the natural flow regime during HHD refill operations may adversely impact spring spawning and incubation success in off-channel habitats that become disconnected.

- The dam flood flow manipulations result in an increase in the duration of flows that scour spawning gravel from the streambed.

- Late summer flows downstream of the Tacoma Headworks (1911) compel many chinook to spawn towards the thalweg rather than the margins, increasing the probability of egg loss due to streambed scour during higher winter flows.

- Late summer low flows and associated shallow water can reduce the number of chinook that spawn in the downstream ends of side channels.

Juvenile Rearing

- Low summer flows reduce the amount of rearing habitat and exacerbate high summer water temperatures.

- Refill operations at HHD have reduced the frequency of side-channel connectivity, which increases the probability that juvenile salmonids may become stranded in side channels that become disconnected from the mainstem. Juvenile chinook have been observed utilizing side channel habitats in the mainstem during the spring (Jeanes and Hilgert 1998).

Downstream Migration

- Refill operations at HHD have reduced flows and prevented spring freshets, which prolong downstream migration of juvenile salmonids. This makes juvenile salmonids more susceptible to predators and adverse water quality conditions. Green River Hatchery chinook smolt releases have higher survival to the Duwamish with increasing flow: only

40% survived at approximately 650 cfs at Auburn while survival rates between 70 and 100% were observed at flows higher than 2,000 cfs (Wetherall 1971).

LOWER GREEN RIVER

Upstream Migration

- The diversions of the White River and Cedar/Black Rivers altered the migration routes of upstream migrating salmonids.

- The combined diversion of the White River and Cedar/Black Rivers reduced the drainage area of the Green River watershed by almost 60 percent. The diversion of the White River reduced summer flows in the lower Green River by roughly 50 percent. The combined diversions results in the loss of physical habitat area such as size of pools, depth of riffles, and an increase in temperature that could delay migration and harm fish.

Spawning and Incubation

- Alterations in the natural flow regime during HHD refill operations may adversely impact spring spawning and incubation success by disconnecting off-channel habitats.

Juvenile Rearing

- Low summer flows adversely impact the amount of rearing habitat and increase high summer water temperatures.

- Juvenile chinook, coho, steelhead, chum, and cutthroat salmonids have been observed utilizing side channel habitats in the mainstem during the spring (Jeanes and Hilgert 2000). Refill operations at HHD have reduced the frequency of side-channel connectivity, which increases the probability that juvenile salmonids may become stranded in side channels that become disconnected from the mainstem.

- The diversion of the White and Cedar/Black Rivers and the construction of revetments reduced the channel width and caused the Green River to form a new, lower floodplain, cutting off access to former off-channel rearing habitats.

- The amount of urbanization increases the frequency, magnitude, and duration of stormwater runoff that adversely impacts salmonid rearing habitat.

MAJOR TRIBUTARIES

Upstream Migration

- The affects of urbanization and groundwater withdrawals have reduced summer low flows, which may delay the upstream migration of adult chinook salmon in Newaukum and Soos Creeks.

Spawning and Incubation

- Impervious surfaces resulting from urbanization increases the volume of stormwater discharged into a stream for a given storm event. This action increases the height of peak flows and creates new peaks where none previously existed, potentially increasing the frequency of scouring and deposition. This further reduces egg and alevin survival.

Juvenile Rearing

- Increases in urbanization and groundwater withdrawals have reduced summer low flows, reducing the amount of available salmonid rearing habitat and exacerbating increases in summer water temperatures (water quality degradation).

- As urbanization increases, the volume of stormwater discharged into a stream for a given storm event also increases. This action increases the height of peaks and creates new peaks where none previously existed, potentially increasing the downstream displacement of emergent fry and reducing quality of overwintering habitat.

PART II: CHAPTER 2.1 ADDENDUM. NATURAL FLOW ANALYSIS

KEY FINDINGS

- Several trends are evident in flow conditions shaped by the Howard Hanson Dam and Tacoma projects. These include an overall decrease in median flow values, and an overall downward shift in flow distributions. These effects no doubt result from the diversion of up to 113 cfs from the river by the Tacoma project and a reduction in flood peaks due to HHD.

- Although one of the original purposes for Howard Hanson Dam was low flow augmentation, it is clear from the analysis that this flow augmentation does not fully overcome the flow reduction effects of the Tacoma diversion during low flow periods. The low flow conditions in the river last longer than they would without the projects in place and the annual minimum flow tends to occur two weeks earlier than without the projects.

- Flood flows have been greatly reduced. Simulated peak flows ranged up to 29,000 cfs under without-projects conditions and 16 percent of annual peaks were greater than 11,000 cfs at Palmer. With the projects in place, none have exceeded 11,000 cfs. The dam has resulted in the managed flood peaks lasting for substantially longer periods of time, albeit at greatly reduced levels.

DATA GAPS

- The natural flow analysis appears to have merit for evaluating hydrologic changes in the Green River and for identifying possible impacts on salmon stocks. Several improvements to the analysis could make it even more useful. The analysis should be updated to reflect changes in HHD operations that have occurred in recent years, especially during the spring refill period. Actual withdrawal records for Tacoma's diversion should be investigated as well. The analysis also could be improved to better simulate short-term high and low flow rates, so that 1- and 3-day annual minima and maxima can be better analyzed.

PART II: CHAPTER 2.2 SEDIMENT TRANSPORT

KEY FINDINGS

The following key findings were identified when reviewing sediment as a factor of decline for salmonids:

UPPER GREEN RIVER

Spawning and Incubation

- Road related sediment yields exceeded 50 percent of background yields in several subbasins in the Lester Watershed Administrative Unit (WAU). In addition, the volumetric proportion of fine sediment was elevated in potential spawning gravels collected from various sites throughout the Lester WAU. High levels of fine sediment smother or trap incubating eggs and alevins and could limit the reproductive success of salmonids. The exact sediment concentrations are being compared to threshold values known to impact the reproductive success of salmonids.

- The Howard Hanson dam is reducing river flow velocities, resulting in sedimentation detrimental to salmonid egg incubation in at least 7.2 miles of river channel.

- Landslides and mass wasting associated with logging practices have led to coarse and fine sediment inputs that fill pools and dramatically increase width-to-depth ratios in streams and rivers, reducing the area of habitat available for juvenile salmonid rearing. Landslides have negatively impacted juvenile salmonid rearing habitat in 2.6 of the 4.7 miles of stream surveyed in the Lester WAU.

MIDDLE GREEN RIVER

Spawning and Incubation

- The upper basin formerly supplied over 90 percent of the alluvial gravel (6,500 to 19,700 tons of gravel per year) to downstream reaches prior to construction of HHD. This gravel is now deposited upstream of the dam (USACE 1998). Entrapment of this sediment behind HHD has resulted in a reduction of suitable spawning gravels in the Middle Green River sub-watershed.

- Howard Hanson Dam operations have increased the frequency and duration of flows between 3,500 and 9,100 cfs, and this increase, in combination with the limited supply of sediment below HHD, may have increased the annual sediment transport capacity by as much as 30% (Dunne and Dietrich 1978).

- The increase in sediment transport capacity has resulted in sediment being carried downstream without being replenished. The channel has incised and an armor layer formed. As of 1993, the armor layer was believed to have moved downstream to RM 40.0, which is near the upstream end of the most valuable spawning area of the Green River. The incision is continuing to move at a rate of approximately 700 to 900 feet per year (Perkins, 1993). As armor layer formation progresses downstream, spawning habitat is lost and channel incision may reduce the amount of available rearing habitat. Rearing habitat is lost by increasing the amount of time that side channels or other off-channel habitats are disconnected from the mainstem.

- Large amounts of fine sediments are released from slides in this sub-watershed and their downstream deposition is detrimental to the successful spawning and incubation of salmonid eggs and alevins. One such slide, near RM 43, was reactivated by a major flood in 1996 (Cropp 1999). This slide is estimated to have delivered up to 50,000 cubic yards of sediment to the channel (Perkins 1998). This slide has been linked to pool filling and degradation of spawning gravels for at least a mile downstream (Cropp 1999).

Juvenile Rearing

- The reduced coarse sediment supply has led to river channel incision. This could reduce the connectivity of important off-channel salmon spawning and juvenile rearing habitat such as side channels, groundwater fed channels, and tributaries.

- Increased fine sediment inputs have been observed to fill pools and the interstitial spaces within substrates near RM 43. This reduces the amount and quality of habitat (i.e., disturbs benthic invertebrate food supply, reduces benthic cover) available for rearing juvenile salmonids and is to be expected downstream of other slide zones in this reach.

LOWER GREEN RIVER

Spawning and Incubation

- The diversion of the White River to the Puyallup River in 1906 reduced the delivery of coarse sediment to the lower Green River by 75 percent. This loss of coarse sediment reduced the availability of suitable anadromous salmonid spawning habitat.

- Increased deposition of fine sediments are filling pools and substrate interstitial spaces, reducing the amount and quality of habitat available for rearing juvenile salmonids.

Juvenile Rearing

- Since the diversion of the White River and the Cedar/Black River, the channel downstream of RM 32 has narrowed by forming a new floodplain within the old channel (Perkins 1993). The new floodplain surface is at least seven feet lower than the former floodplain (Dunne and Dietrich 1978).

- This lowering has disconnected off channel juvenile salmonid rearing habitat. This change has been compounded further and masked by the construction of levees.

MAJOR TRIBUTARIES

Upstream Migration

- The increased sediment delivery to alluvial fans and low gradient reaches of the Green River, in combination with the decrease in low flows, impedes adult chinook attempting to migrate upstream into tributaries.

Spawning and Incubation

- Newaukum Creek represents an important source of coarse sediment to the Middle Green River (Perkins 1993). In contrast, most of the coarse sediment transported by Soos Creek settles out in low gradient reaches prior to reaching the Green River (King County 1989).

- Increased fine sediment delivery and deposition into low gradient reaches of the tributaries reduces salmonid reproductive success. High levels of fine sediment can smother or trap incubating salmonid eggs and alevins.

Juvenile Rearing

- The increase of fine sediment inputs may fill pools and the interstitial spaces within substrate. This results in a reduction of the amount and quality of habitat (e.g., disturbed benthic invertebrate production, reduced benthic cover) available for rearing juvenile salmonids.

DATA GAPS

- Watershed-wide sediment contribution information at the sub-watershed scale was not available.

- The downstream progression of the armor layer on the mainstem has not been estimated for almost ten years.

PART II: CHAPTER 2.3 HYDROMODIFICATION

KEY FINDINGS

The following key findings were identified when reviewing hydromodification as a factor of decline for salmonids:

UPPER GREEN RIVER

- High sediment supply has transformed portions of the mainstem Floodplain channel type from pool-riffle to braided morphology. Braided channels experience frequent scour of a depth sufficient to damage or destroy chinook redds and have low pool frequencies, reducing the amount of juvenile rearing and adult holding habitat.

- Inundation by Howard Hanson Reservoir has transformed 4.5 miles of former Floodplain channel type (18% of total in Upper Green River sub-watershed) to periodic Lacustrine habitat and has resulted in the loss of 10,000 linear feet of side channel habitat.

- Armoring of channel banks to protect transportation corridors (roads and railroads) has reduced the complexity and quality of rearing habitat in approximately 6.3 miles (26%) of the remaining Floodplain channel type in the Upper Green River sub-watershed.

- Large woody debris (LWD) loadings in the Upper Green River sub-watershed are currently rated as “not properly functioning” or “fair” to “poor” according to criteria developed by the National Marine Fisheries Service (NMFS) (NMFS 1999) and Washington Department of Natural Resources (DNR) (WFPB 1997). LWD that contributes to “fair” rating is generally small and does not include “key” pieces. The low LWD frequencies correspond with low pool frequencies, indicating that the lack of LWD in Floodplain channels known to be responsive to LWD has degraded rearing and adult holding habitats required by chinook, coho, and steelhead salmonids.

- Large pieces of LWD (up to 90 feet long) were previously mobilized and transported downstream through Floodplain channels in the Upper Green River sub-watershed. Downstream transport of LWD has been interrupted by HHD since 1964.

MIDDLE GREEN RIVER

- The total length of Floodplain channel type between RM 58 and RM 61 has declined by approximately 0.5 miles (15%) as a result of road/railroad construction and flood control by HHD. This has resulted in a loss of habitat used by adult chinook and steelhead for spawning, rearing, and adult holding. Coho, cutthroat, and probably chum would use this area for rearing and possibly some spawning.

- Bank armoring to protect transportation corridors has reduced the complexity and rearing habitat value over 1.6 miles (26%) of the Large Contained channel between RM 61 and 64.5. Channel constraints in this segment generally affect only one bank, and have not substantially reduced the ability of this channel to form side or off-channel habitats due to the naturally high confinement (valley width <2 times channel width) of this channel type.

- Construction of levees and revetments to prevent bank erosion and control flood levels has reduced the complexity and rearing habitat value over approximately 5.6 miles (40%) of the Middle Green Floodplain segment between RM 31 and RM 45. Levees and revetments generally affect only one bank in this segment, and thus have not altered the overall channel type.

- The length of channel characterized by a braided morphology between RM 31 and RM 45 declined from 10.4 miles to less than 4 miles from 1936 to 1992 (60% reduction). Reduced area of braided morphology represents an improvement in the stability of spawning habitat, as braided channels typically experience extensive scour on an annual basis.

- The area of active gravel bars in Floodplain segments of the Middle Green River has declined as a result of flood control by Howard Hanson Dam. All 10 acres of formerly active bar surface between RM 56 and RM 61 now support riparian forest communities. Bar area in the Floodplain channel segment between RM 31 and RM 45 declined from 236 to 78 acres (67% reduction) between 1936 and 1992. The loss or stabilization of bar surfaces corresponds with a reduction in shallow marginal habitat and suggests that creation of new side channel habitats and riparian forest stands has been slowed or halted.

- LWD is currently scarce in Floodplain channel types known to be responsive to LWD. No LWD was observed in the Floodplain channel segment between RM 58 and RM 61 on aerial photographs from 1953 and 1987. LWD in the Middle Green Floodplain segment (RM 31 to RM 45) currently averages only 32.6 pieces per mile, even with LWD placement undertaken in recent restoration projects. NMFS criteria for "properly functioning habitat require at least 80 pieces per mile. The lack of LWD corresponds with a scarcity in large pools, which numbered less than 0.12 pools per channel width based on evaluation of air photos from 1992 (Fuerstenberg et al. 1996). The scarcity of LWD and pools indicates that the quality and quantity of mainstem rearing and adult holding habitat has declined in Floodplain channel types.

- The length of side channel habitats in the Floodplain segments of the Middle Green River has declined by over 70 percent as the result of the disconnection of 1.7 miles of side channel between RM 58 and RM 61 from 1953 and 1987, and the loss of 13.8 miles of side channels between RM 31 and RM 45 from 1906 to 1992.

- Decreased flood flows, road and railroad construction, and levees and revetments are believed to have reduced the area of floodplain inundated on a regular basis (by 2-year return interval flood). Available data are insufficient to quantify the magnitude of the reduction.

LOWER GREEN RIVER

- Six miles of Floodplain channel type and 14 miles of Palustrine channel type have been channelized. Both Palustrine and Floodplain channel types typically have complex plan-forms and dissipate flood energy by overbank flows. Consequently, channelization has presumably resulted in the loss of almost all mainstem winter rearing habitat and a reduction in the quality of summer rearing and adult holding habitat in these segments.

- All 36 acres of gravel bars (100%) in the former Floodplain channel segment (RM 25 to RM 31) have been lost. These sites formerly provided shallow marginal habitat, increased channel complexity, and sites suitable for colonization by riparian hardwood forests.

GREEN/DUWAMISH ESTUARY

- Diversion of the White and Cedar/Black Rivers from the Green/Duwamish River has reduced the freshwater inflow to the estuary by about two-thirds and has led to profound changes in the nature of the Duwamish River channel and adjacent floodplain.

- Creation of the Duwamish Waterway resulted in replacement of about 9.3 miles of meandering river with 5.3 miles of straightened channel.

- Approximately 98 percent (2.2 mi^2) of the Duwamish River's historic floodplain marshes and intertidal mudflats have been replaced with fill, overwater structures, commercial and industrial facilities, and other development.

- A large proportion of the shoreline downstream of RM 5.3 and around Elliott Bay has been armored in some way and much of this shoreline also is altered by the presence of overwater piers and wharves.

- Despite the straightening of the river and loss of intertidal habitat, the Duwamish River and Elliott Bay still have some areas of mudflats that provide important estuarine rearing functions for juvenile salmon.

- Recent habitat management policies and restoration projects, as well implementation of requirements for mitigation for any new losses of habitat, have begun to address the degraded conditions along the Duwamish River.

MAJOR TRIBUTARIES

- The lower 0.3 miles of Newaukum Creek have been dredged and straightened by private landowners.

- Stream cleaning and riparian harvest have reduced the frequency of LWD in the lower 1.4 miles of Newaukum Creek to 0.3 pieces per channel width, a level considered “poor” or “not properly functioning”. Pools are also scarce.

DATA GAPS

- No quantitative data on the extent or quality of side channel habitat exist for the Upper Green River sub-watershed. SSHIAP recently mapped side in the Upper Green sub-watershed using 1:12,000 aerial photos from 1995/1996, but these data have not been field verified. Data should be available soon.

- Available data are insufficient to assess the reduction in floodplain area throughout the WRIA.

- There are no existing data on the quality of off-channel habitat.

- No quantitative field data on pool frequency, channel morphology, substrate, or bank condition in the mainstem (with the exception of the Upper Green River sub-watershed) exists. Changes from historic conditions are speculative and based on general characteristics of the various channel types.

- No data on LWD in the lower Green River (RM 11 to RM 25) or Green River gorge (RM 45 to RM 31) exists.

- Limited data are available on hydromodifications or habitat in Soos and Newaukum Creeks. SSHIAP is in the process of conducting a hydromodification assessment that will include all tributaries mapped on the 1:24,000 DNR hydrography. The assessment will quantify the stream length affected by artificial confinement (levees, bank armoring, adjacent roads/railroads, etc.) and ditching (channelization, straightening, etc.).

PART II: CHAPTER 2.4 RIPARIAN FUNCTION

KEY FINDINGS

Riparian condition was assessed based on vegetation type, size, and density, generally corresponding with methodologies from the Salmon and Steelhead Inventory and Assessment Program (SSHIAP) and the Washington Forest Practices Board Manual (WFPB 1997). In areas where no existing riparian data were located, an original assessment was conducted specifically for this report. The original methodology is described in the chapter text. The following key findings were identified when reviewing riparian functions as a habitat factor of decline for salmonids:

UPPER GREEN RIVER

- At least 33 percent of the riparian zone has conditions that would be expected to result in poor bank stability. Bank stability may be further compromised by increased sediment delivery and in-channel storage.

- Almost 50 percent of the channel length is currently bordered by a riparian zone that is classified as providing poor shade. None of the riparian zone along the mainstem Green River is sufficient to provide good shade conditions.

- The ability to supply organic matter and filter sediments is rated poor along approximately 35 percent of the channel.

- Large woody debris recruitment is currently rated poor along almost 50 percent of the river and is not considered to be good anywhere along the mainstem Green River in the Upper Green River sub-watershed.

- Seasonal inundation by Howard Hanson Dam reservoir and the permanent presence of roads and railroads within the riparian zone will hinder recovery of riparian functions along approximately 12 miles of the mainstem Green River.

MIDDLE GREEN RIVER

- Almost 25 percent of the riparian zone has conditions that would be expected to result in poor bank stability.

- Almost 30 percent of the channel length currently is bordered by a riparian zone that is classified as providing poor shade. Sixty-five percent of the riparian zone classified as having good shade conditions is located within the Green River gorge.

- The ability to supply organic matter and filter sediments is rated poor along approximately 27 percent of the channel.

- Large woody debris recruitment is currently rated poor along almost 38 percent of the river. The 22.6 miles of riparian zone considered to have good LWD recruitment are located almost entirely within the Green River gorge.

LOWER GREEN RIVER

- Levees and revetments have fixed the channel in place and effectively prevent bank erosion where channel migration would occur naturally. This stops an important mechanism of LWD recruitment to the river.

- Over 80 percent of the riparian zone currently is considered to provide poor shade, organic matter recruitment, and sediment filtration.

- Ninety-seven percent of the riparian zone is considered to have poor LWD recruitment potential and microclimate conditions. None of the riparian zone along the lower Green River is considered to have good LWD recruitment potential.

- Almost 50 percent of the riparian zone is comprised of forbs and grass, or shrubs, many of which are non-native.

- Pavement and bare ground account for approximately 33 percent of the total area within 300 feet of the river in this sub-watershed.

GREEN/DUWAMISH ESTUARY

- The majority of the upper intertidal zones in both the estuary and in Elliott Bay are sup-planted with riprap, seawalls, and overwater structures.

- The upper estuary between RM 5.3 to RM 11.0 supports the largest proportion of riparian vegetation, although these stands are not wide enough to provide high quality riparian functions.

- Riparian vegetation is sparse in the lower estuary (RM 5.3 to the mouth).

- Functional riparian stands on Elliott Bay are limited to Magnolia Bluff and represent less than 14 percent of the bay shoreline.

- The remaining riparian areas of the lower estuary and bay are dominated by overwater and inwater structures.

MAJOR TRIBUTARIES

- Sections of intact riparian zone that currently support small- to medium-sized deciduous and mixed conifer and deciduous trees are concentrated in the canyon section of Newaukum Creek from RM 0 to 3 and on Soos Creek from RM 1.5 to 2.8.

- Bank stability, shade, and organic matter recruitment are considered poor along approximately 65% to 80% of Soos Creek and 53 % of Newaukum Creek.

- None of the riparian zone along Soos Creek is currently considered to provide good LWD recruitment.

- Sixty percent of the riparian zone along Newaukum Creek currently provides poor LWD recruitment. The remaining 40% of the riparian zone analyzed currently has fair LWD recruitment and may develop good conditions if left undisturbed.

- Impacts to riparian functions along mainstem Soos Creek from RM 0.0 to 13.0 occur primarily as a result of urban (including powerline corridors and roads) or residential development adjacent to the stream.

- Impacts to riparian functions along mainstem Newaukum Creek from RM 0.0 to 10.0 occur primarily as a result of agricultural or residential development adjacent to the stream.

DATA GAPS

- A field reconnaissance of riparian conditions using a consistent methodology designed for application at the appropriate stream/river scales has not been conducted for most of the watershed.

PART II: CHAPTER 2.5 FISH PASSAGE

KEY FINDINGS

The following key findings were identified when reviewing fish passage as a factor of decline for salmonids:

- There are no known natural impassable barriers in the mainstem Green River up to RM 93. The historic upstream extent of anadromous salmonid use is presumed to have been around RM 93 based on an analysis of river gradient and a series of mapped cascades.

- The earliest documented anthropogenic barrier on the mainstem Green River was a wooden weir erected annually from 1904 to 1924 on the mainstem Green River at the confluence of Soos Creek to allow capture of adult chinook in the mainstem.

- The Tacoma Headworks, which began construction in 1911 and was finished in 1913, was the first permanently constructed barrier to adult salmon and steelhead in the Green River. This dam has blocked anadromous salmonids from natural migration and reproduction in the Upper Green River sub-watershed for nearly 90 years.

- Salmonids that are not naturally produced (e.g., hatchery planted juveniles), juveniles from adult steelhead that were transported upstream of the dams, or resident trout may migrate downstream past Tacoma's existing Headworks. Most pass over the dam spillway, where there is a potential for fish to be injured. The second avenue of passage available at the Headworks is the pipeline intake. The existing Headworks intake screens do not meet NMFS or State screen criteria (1/4" mesh size from center strand to center strand, with 5/32" openings) and juvenile salmonids can potentially be impinged on the intake and killed; very small juvenile salmonids could pass through the existing screens.

- Howard Hanson Dam completed construction in 1962 at RM 64.5 and represents another complete barrier to the upstream passage of anadromous and resident fish.

- There are two main concerns regarding downstream fish passage associated with Howard Hanson Dam: (1) passage through the dam, and (2) passage through the reservoir:

  (1) The low survival rate of fish passing through Howard Hanson Dam is primarily a function of two factors: 1) the spring refill operation strategy, which influences the ability of fish to locate the outlets; and 2) the low survival of juveniles passing

through the bypass outlet pipe. Current annual survival of juvenile salmon and steelhead migrating through HHD outlets is estimated to be between 5 and 25 percent based on a fish passage model and on-site monitoring data (Dilley and Wunderlich 1992, 1993). Out-migrant studies indicate that there is little or no injury to juvenile fish using the radial gates (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992; 1993), but injury rates through the bypass pipe range from 3 to almost 90 percent, depending on species and environmental conditions.

(2) Aitkin et al. (1996) found that migration of juvenile coho salmon through Howard Hanson Reservoir took a significantly longer time at both mid- and high-pool elevations. Travel times for both coho and steelhead smolts were longest at mid-pool. Travel time was more closely related to refill rate than pool level, increasing as refill rate increased. Survival of fish passing through the reservoir has been identified as a concern, but cannot be assessed using existing data.

- Recent high levels of coarse sediment inputs upstream of HHD and alterations in the flow regime downstream of HHD have transformed sections of floodplain channel types from essentially a single-thread pool riffle channel morphology to a braided morphology consisting of numerous shallow flow paths. These shallow paths are most likely to adversely affect juvenile coho and steelhead rearing in the mainstem and adult chinook salmon moving upstream in August and September when flows are generally lowest. Mainstem low flow concerns have been documented in the middle Green River between RM 31 and RM 45 and in the upper Green River near RM 83.

- Low flow concerns have been identified at the mouths of several of the Green River's tributaries, including Newaukum Creek and a number of streams in the upper watershed. This is largely due to the porous nature of alluvial fans. Water flowing across these fans is rapidly lost to seepage, and flows may disappear before reaching the foot of the fan (Levin 1981). An increase in channel sediment from logging in the Upper Green River sub-watershed, lower flows in the Middle Green River, and low levels of LWD in both reaches have exacerbated low flow concerns and may impede passage of adult salmonids.

- Subsurface flows have been observed in the North Fork Green River during late summer (Noble 1969; Hickey 2000b), and could prevent salmonids from entering the river or moving upstream. Operation of the North Fork well-field by Tacoma could reduce flows in the North Fork, although there currently are insufficient data on the extent of this potential impact.

- Water quality degradation can pose significant barriers to salmonid migration. Temperatures that exceed the optimum range identified by NMFS have been observed throughout the watershed from the upstream end of Howard Hanson Reservoir to the estuary. Temperatures exceeding potentially lethal limits have been measured in the lower Green River and Green/Duwamish estuary. As late as 1985, kills of adult chinook were reported in the Green/Duwamish estuary presumably from inadequate water quality parameter(s) that are not specified in this report

- In 1958, an earthen dam was constructed on the Black River, 1000 feet upstream from the Green River. Besides impeding salmonid migration into the Springbrook Creek system, this dam blocked flows from the Green River from backwatering into the remnant Black River, which could have provided some refuge habitat for salmonids during high flows. In 1972, the US Soil Conservation Service replaced the dam with the Black River Pumping Station (BRPS), which currently is operated by King County. Although it is equipped with upstream and downstream fish passage facilities, the BRPS can act as a barrier to migration of juvenile and adult salmonids due to inadequate screening, fishway design, and operation schedule.

- Adult salmonids cannot pass downstream via the downstream fish passage facility at the BRPS. Chinook salmon have been known to move upstream and become trapped in the Springbrook Creek system, where there is little if any suitable chinook spawning habitat.

- Streamside recreation or fish viewing activities have been observed to reduce the rate of upstream coho migration in the middle and lower Green River (Malcom 1996). In-water activities such canoeing have also been observed to displace adult coho salmon downstream (Malcom 1996). In addition to direct disturbances, mammalian odors, such as those arising from dogs and people, have been observed to temporarily disrupt and slow the upstream migration rate of adult coho and chinook salmon. Salmon will expend energy as they are displaced downstream and then, must again expend energy to move back upstream. In portions of the river with elevated temperatures, the energy loss and stress have the potential to increase pre-spawn mortality and reduce reproductive success. Displacement of salmon from redds may result in incomplete redd construction, selection of less preferred redd sites, and incomplete spawning.

DATA GAPS

- There is limited information on the location of natural barriers or historical fish distribution, particularly for the Upper Green River sub-watershed

- There is little information available to assess the historic impacts of operation of Tacoma's North Fork well field on fish passage in the North Fork Green River.

- The available information is inadequate to assess survival through Howard Hanson Reservoir.

- The rate of injury or mortality (if any) for fish passing the existing Tacoma Headworks is unknown.

- Data on fish passage barriers and other physical habitat in Newaukum and Soos Creeks is incomplete. This lack of physical habitat information is a WRIA-wide data gap for all tributary and mainstem reaches.

PART II: CHAPTER 2.6 NON-NATIVE SPECIES

KEY FINDINGS

The key findings on exotic plants and animals in the Green/Duwamish estuary, mainstem Green River, and major tributaries are listed below:

- Although adult Atlantic salmon, which have escaped from the commercial net pen industry, occasionally swim into the estuary and up the Green River, no juvenile Atlantic salmon have been observed in the system.

- Exotic warmwater fish are known to be present in lakes that drain to the mainstem Green River, but observations of these fish in the river are limited.

- Nutria and bullfrogs are the only exotic aquatic animal species other than fish observed in the Green River watershed upstream of the tidally influenced zone.

- In the Green/Duwamish Estuary, three exotic benthic invertebrates are known to occur - the amphipod *Grandidierella japonica*, the tanaid *Sinelobus stanfordi*, and the cumacean *Nippoleucon hinumensis.*

- Some riparian areas are dominated by dense colonies of exotic vegetation, such as blackberry, reed canary grass, and Japanese knotweed.

DATA GAPS

- No program exists that routinely monitors for or documents the presence and location of exotic species in the Green River watershed.

- The overall implications of non-native species invasions are not well understood.

PART II: CHAPTER 3. TRIBUTARIES WRIA-WIDE

KEY FINDINGS

- There is a general lack of physical habitat information for tributary streams.

- Most of the tributary streams downstream of Newaukum Creek are undergoing a conversion from forest and rural to a more urbanized environment.

- The riparian buffer of most tributary streams downstream of HHD is insufficient and is limiting natural salmonid production.

- There is a general lack of LWD throughout the tributary streams.

- High winter flows in streams in urbanized settings limit the reproductive success of salmonids because of scour and bedload movement and lack of refugia.

- Channelization of many stream reaches has eliminated stream channel complexity and limits natural production of salmonids.

- Summer low flow discharges are decreasing in some subbasins, which limits salmonid production of those species that have life history rearing trajectories that require over-summer rearing.

- In spite of the habitat degradation of most of the tributary streams, they are still important contributors to salmonid production.

DATA GAPS (H2)

- Information on numerous tributaries was not located or made available during the course of this investigation.

- There is a general lack of physical habitat information for tributary streams.

- Comprehensive barrier surveys need to be completed throughout the watershed.

- The impact of non-native and invasive aquatic plants on naturally producing salmonids is not well understood.

- Use and importance of specific streams as overwintering refuge habitat for juvenile salmonids from high mainstem flows is not fully known.

- While LWD is generally lacking throughout the tributary streams, the amount and type of LWD that is present is not well documented.

- The actual amount of loss of streambed channel and complexity after channel relocation is not known.

- The quality of the sediments in the tributary streams is not fully known.

PART II: CHAPTER 4. ESTUARY AND NEARSHORE CONDITIONS

The information below is a summary of preliminary findings on salmonid factors of decline as determined in the draft *Reconnaissance-level Assessment of the State of the Nearshore Report* (SONR). The draft SONR gathers together existing information about selected nearshore and estuarine habitats and species, providing a summary of what is known about the nearshore ecosystem in WRIA 9. Because the SONR is still in draft form, all information below is considered **preliminary and subject to change**. Readers are strongly encouraged to refer to the final document, which is scheduled for publication in January 2001.

KEY FINDINGS

- Early salmonid survival and growth can be an important determinant of adult returns. This is the life stage that the nearshore environment supports.

- The nearshore environment provides migratory corridors, nursery areas, feeding and prey production areas, refuge, and habitat for the physiological transition from fresh to salt water environments for juveniles of all species of salmonids.

- The nearshore provides migratory corridors, staging and feeding areas, and habitat for the physiological transition from salt to fresh water environments for adult salmonids.

- All anadromous salmonids utilize and depend upon the nearshore. Of the salmonid species, chinook and chum salmon rely most heavily upon the nearshore environment.

- A wide variety of habitats in the nearshore are important to salmonids, including but not limited to eelgrass beds, kelp forests, flats, tidal marshes, subestuaries, beaches and backshores, and marine riparian vegetation.

- Sediment transport processes are critical for maintenance of important nearshore habitats.

- In WRIA 9, shoreline armoring and shoreline development have interrupted these processes. Approximately 75 percent of the WRIA 9 shoreline is armored.

- Eelgrass, kelp, marsh, flat, subestuary, beach and backshore habitats, and riparian vegetation, critical for juvenile salmonid support in the migratory corridor, have been lost. For example, 98 percent of the marshes and flats, and 100 percent of tidal swamps, have been removed from the Duwamish River.

- Shoreline armoring, dredging, filling, and overwater structures have contributed to much of this loss of habitat in the migratory corridor.

- Significant amounts of marine riparian vegetation have been lost from WRIA 9 shorelines. The Washington state Department of Natural Resources ShoreZone program estimates that only 11 percent of WRIA 9 shorelines have trees overhanging the intertidal zone. This loss may indicate a significant loss of critical functions that support salmonid habitat.

- Commercial, industrial, and residential development have contributed toxic sediments, chemicals and organic compounds to the water and sediments of the nearshore environment in WRIA 9. The Duwamish River is the most heavily contaminated portion of the WRIA 9 nearshore.

- Non-native species may be detrimental to salmonid survival in the nearshore in WRIA 9, but more data are necessary to identify specific effects of particular species.

DATA GAPS

- There is very limited data on the residence time or migration rates of juvenile salmonids in the nearshore.

- While scientists agree that juvenile salmonids use a variety of habitats in the nearshore, little detailed information is available. Actual juvenile salmonid use of eelgrass, kelp, flats, tidal marshes, subestuaries, beaches and backshore areas, are major data gaps.

- The complete functions and values of marine riparian vegetation are not fully understood.

- The carrying capacity of natural and altered nearshore habitat for salmonid support is not fully understood.

- Very little is known about the cumulative effects of interrupting natural sediment transport processes in the nearshore.

- Although shoreline armoring is very widespread in the nearshore environment, few studies address the effects of armoring on nearshore biota over the long term. Similarly, little is known definitively about the cumulative effects of shoreline armoring on the nearshore environment.

- Surveys of forage fish spawning areas are incomplete and stock assessments are absent.

- Little is known of the cumulative effects of loss of habitat in the migratory corridor on juvenile salmonids.

- The details of juvenile salmonid use of nearshore habitats are not well understood.

- Complete maps of nearshore habitats do not exist in all areas.

- Very little data on the functions and values of marine riparian vegetation exists.

- Sublethal effects of sediment and water contaminants on salmonids and other nearshore organisms are not known.

- Non-native species may be detrimental to salmonid species' survival in WRIA 9, but more data are necessary to identify specific effects of particular species.

- Assessment methods for evaluating habitat quality and for directing mitigation, restoration, preservation, and enhancement efforts are lacking.

PART III: SUMMARY

2. Conclusions

2.1 Principles to Guide Salmonid Recovery

2.2 Strategy: Unlock the Natural Potential

2.3. Specific Action Recommendations

2.1 PRINCIPLES TO GUIDE SALMONID RECOVERY

2.1 PRINCIPLES TO GUIDE SALMONID RECOVERY

The Technical Committee recognizes that habitat management itself cannot recover depressed salmonid populations, but it is one of the necessary steps of recovery. The salmonid populations of the Green River Basin (WRIA 9) evolved in an environment that itself was shaped over the last 10,000 years. Over the last 150 years, the environment of the Green River Basin has been highly modified. Many of the ecosystem processes that were historically present and are necessary for successful salmonid production have been interrupted. The protection of existing properly functioning ecosystem processes and restoration of essential degraded processes in the freshwater, estuarine and marine environment is necessary for successful salmonid recovery. These efforts will reestablish the ecosystem processes that helped shape salmonid evolution and should maximize the chances for salmonid recovery. Without these changes, the successful recovery of naturally producing salmonid populations is highly unlikely.

Over the last several decades, scientists across the Pacific Northwest had been learning about the needs of salmonids and the role of the freshwater and nearshore habitats in their life histories. While still growing, the resulting body of knowledge has produced a number of well-accepted ecological principles and goals regarding salmonid conservation needs. The authors of this report have drawn from this accumulated wisdom a set of principles relevant to salmonid recovery in WRIA 9. The sources of these principles, shown below, include a number of widely accepted documents. The references in brackets indicate the pages that list the principles/goals:

- Coastal Salmon Conservation: Working Guidance for Comprehensive Salmon Restoration Initiatives on the Pacific Coast - National Marine Fisheries Service (1996) [pages 12-13]
- An Ecosystem Approach to Salmonid Conservation, Spence, Lomnicky et al. (1996) ("ManTech Report") [pages 191, 202-203]
- Return of the Kings: Strategies for the Long-Term Conservation and Recovery of the Chinook Salmon – King County's Response Report to the proposed Endangered Species Act Listing (March 1999) [Chapter 2; page 3]
- Initial Snohomish River Basin Chinook Salmon Conservation/Recovery Technical Work Plan, Snohomish Basin Salmonid Recovery Technical Committee (October 1999) [Chapter VI; pages 76-77]
- Ecological Principles, Christopher Frissel, 1997. In Williams et al., Watershed Restoration: Principles and Practices. American Fisheries Society. [Chapter 7, pages 96-115]

The following is a <u>non-prioritized</u> list of the principles that the Technical Committee believes should underlie the proposed strategy for WRIA 9 and specific action recommendations:

- Protect and maintain existing physical, chemical, and biological processes and the habitats they form as well as restoring those that have been degraded or lost;

    - Protect and restore the natural ecosystem processes responsible for creating habitats required by salmonids;

- Protect and restore those habitats that are necessary during all life stages of salmonid development;
- Maintain quality habitats that function as refugia from which salmonid populations may expand;
- Maintain the corridors (connectivity) that link habitats and emphasize the (re)connection of freshwater, estuarine, and saltwater habitats and their associated zones as required by salmonids during all life stages;
- Adopt an ecological approach to maintaining, improving, and restoring freshwater, estuarine, and saltwater habitats and their associated zones;

- Emphasize self-sustaining runs of naturally-spawning salmon when developing protection and restoration strategies;
- Preserve protection and restoration/rehabilitation opportunities of critical habitats; and
- Employ scientifically rigorous adaptive management techniques to all elements of recovery activities for WRIA 9.

2.2 STRATEGY FOR MULTI-SPECIES SALMONID RECOVERY IN THE GREEN/DUWAMISH WATERSHED:

Unlock the Natural Potential

WRIA 9

Habitat Limiting Factors and Reconnaissance Report
December 2000

2.2 STRATEGY

INTRODUCTION

The WRIA 9 technical committee has developed a strategy to help set initial actions for salmonid conservation and recovery in the Green/Duwamish River watershed of WRIA 9*. This strategy is based on the ecological principles discussed in this chapter and the habitat limiting factors discovered to date in WRIA 9. This is the first step to help focus future research, preservation, and restoration activities in the Green/Duwamish watershed.

> *"In environmental planning and management, it is important to distinguish between strategy and tactics (Bella and Overton 1972). Strategy concerns the comprehensive, large-scale marshaling and allocation of resources, whereas tactics concern local, immediate, and short-term activities. It is critical that tactics be congruent with, and directed by, an overall strategy. It is also necessary that strategy be shaped by the limitations of tactical capabilities." (Frissell, 1997)*

THE STRATEGY

The natural production of anadromous salmonids for the Green/Duwamish River watershed currently is limited to the Middle Green River (RM 64.5 to 32), Lower Green River (RM 32 to 11), and Duwamish River(RM 11 to 0) Subwatersheds, as well as the estuarine and marine waters. Two mainstem dams pose complete upstream barriers and keep anadromous salmonids from migrating to the Upper Green River subwatershed (RM 93+ to 64.5). A key component to realizing the recovery potential of the watershed will be efficient passage at the dams for both adults and juveniles. Efficient passage will dramatically increase available spawning and rearing habitat, especially for coho, steelhead and chinook salmon and possibly result in equal response in juvenile production. Another key component will be having adequate downstream habitat support that allows this potential increase in juveniles to complete their life cycle.

* Not included in this strategy is that portion of WRIA 15 known as Vashon-Maury Island (Vashon-Maury Island is included in WRIA 9 for planning purposes.) and tributaries along the west side of WRIA 9 that feed directly to the Puget Sound. Generally, a paucity of habitat information for the streams of Vashon and Maury Islands precludes an opportunity for an adequate assessment and development of a suitable strategy at this time.

PRECARIOUS STATUS QUO

The Lower Subwatersheds currently produce chinook, steelhead, coho, chum, cutthroat and some sockeye and pink salmon. This habitat must be maximized for the watershed to reach its potential. Some salmon stocks, such as chinook, appear to be stable due to recent escapement estimates yet the habitat has declined severely and steadily in these lower reaches. The dichotomy between apparently stable runs of some salmon vs. the documented habitat degradation has resulted in a precarious existence for naturally produced salmonids. Some of the primary limiting habitat factors (LHF) for each subwatershed and the salmonid species present have been briefly listed below:

MIDDLE GREEN RIVER SUBWATERSHED (RM 64.5. TO 32.0):

MAINSTEM LHFS & IMPACTS

- Dams, revetments, residential and agricultural land use resulting in: water withdrawals, changes in the natural flow regime; sediment starvation and scouring, loss of side channel and other off-channel habitats, loss of riparian habitat functions. Salmon species affected: Chinook, steelhead, coho, chum for spawning, some pink and sockeye. All species (including cutthroat) use for migration and feeding.

TRIBUTARY LHFS AND IMPACTS:

- Residential, agriculture and some urban development resulting in: wetland and riparian function removal and increasing impervious surfaces leading to hydrologic disruption to stream flow, channel degradation and decreased water quality; re-channeling streams and limiting their lateral migration to facilitate roads and protect property; removal of in-channel wood, barriers to migration.

CURRENT SALMONID USE:

- Mostly coho and cutthroat, some chinook, steelhead and chum, a few sockeye.

LOWER GREEN RIVER SUBWATERSHED (RM 32.0 TO 11.0):

MAINSTEM LHFS AND HABITAT IMPACTS

- Urbanization, the 1906 diversion of the White River from the Green River, dam flow manipulation and revetments resulting in: lowering of floodplain and disconnection of off-channel habitats such as sloughs and adjacent wetlands; reduction of instream complexity (wood), pools and riffles; barriers from flood control gates and chronic water quality problems; severely reduced riparian functions.

CURRENT SALMONID USE:

- Upstream and downstream migration and rearing for all species, some chinook salmon and steelhead spawning.

TRIBUTARY LHFS AND IMPACT

- Intense urbanization and infrastructure support: resulting in loss of forest cover and increased impervious surfaces which in turn result in unstable streambed channels and disruption to the natural flow regimes; roads and associated runoff and barriers; Water quality degradation; loss of riparian function; stream channelization for facilitating efficient agriculture and urbanization; non-native plant and aquatic species.

CURRENT SALMONID USE:

- Many tributaries can no longer maintain self sustaining runs, although some coho and cutthroat still use select tributaries. Some of the tributaries, especially near their confluence with the mainstem, may provide important rearing habitat for juvenile salmonids borne in other areas of the watershed.

GREEN/DUWAMISH ESTUARY SUBWATERSHED (11.0 TO 0.0):

MAINSTEM LHFS AND IMPACTS

- Urbanization/industrialization has resulted in: Dredging/channelization and filling 97% of the estuarine mudflats, marshes and forested riparian swamps; the remnant, shortened channel has been simplified and polluted by industry, stormwater and wastewater effluent.

CURRENT SALMONID USE:

- All species migrate, rear, and acclimate in this transitional area between river and marine waters. Juvenile chinook and chum salmon are most dependent on this type of habitat. Small numbers of char adults have been consistently documented to use this reach.

TRIBUTARY LHFS AND IMPACT:

- Aggressive development has made many tributaries inaccessible and inhospitable for salmonids. Most of the small patches of remaining marginal habitat are disconnected and heavily impacted by stormwater-associated flows and poor water quality. Functional riparian areas have been eliminated or fragmented to a few undeveloped areas.

CURRENT SALMONID USE:

- Some cutthroat and coho are observed in a very few streams, most are incapable of producing a self-sustaining run.

WRIA NEARSHORE:

Much of the estuary shoreline has been filled, hardened, or replaced with bulkheads. Extensive areas have been dredged to maintain navigation along piers and within marinas. The supply of beach sediment has been curtailed and water quality problems stemming from upland areas are affecting nearshore habitats. Riparian areas are absent or no longer function to support salmonids in the Green\Duwamish and other Puget Sound watersheds.

CURRENT SALMONID USE:

- Many species of juvenile salmonids, such as chinook, chum and pink salmon, are dependent on the nearshore for rearing prior to their rigorous ocean migration.
- The nearshore also produces important food items for all life stages of salmonids, especially important are the bait fish (i.e., sand lance, surf smelt, and herring) which require this area to spawn.

- The wide geographic scale and severity of the habitat loss implies that the apparent stability of naturally produced salmonid adults, such as chinook, is precarious at best and masked due to hatchery-produced adults that stray onto the spawning grounds. The principal hatchery operation itself is threatened by water quality degradation caused by rapid development in the Soos Creek subasin upstream from the hatchery. An understanding of the natural production capacity – that is, production minus the contributions of hatcheries - in the existing WRIA 9 fresh and salt-water ecosystems is a priority data gap that is only beginning to be addressed.

UNLOCK THE NATURAL POTENTIAL

To recover salmonids in the face of this precarious status quo, we must unlock the natural potential of the Green/Duwamish watershed, maintain and enhance currently functioning habitat and search for opportunities to increase salmonid survival, especially in the Lower and Duwamish Subwatersheds.

The Upper Subwatershed (RM +93.0 to 64.5) holds the greatest potential for increasing natural salmonid production. Dams have blocked fish access to approximately 106 lineal stream miles and half of the Green-Duwamish River watershed acreage. The Upper Subwatershed contains many reaches of suitable spawning and rearing habitat, especially for chinook, steelhead, coho and cutthroat salmonids. This reach is not pristine, it has been adversely affected by logging, a dam, roads, a railroad, water withdrawals and reservoir flooding. Although, because of the limited range of land use practices and distance from population centers many of the basic habitat forming processes such as sediment transport and flow regimes can be recovered. This subwatershed is also large enough to function as salmonid refugia (Frissel, 1997) that can seed the precarious downstream habitat once efficient passage is provided through the dams. This is particularly important since the Lower Subwatersheds may no longer have the capacity to naturally rebound from disturbance events.

Restoring and reconnecting the Upper Subwatershed through efficient passage at the dams could dramatically increase the number of naturally produced juvenile salmonids. However, success in realizing this potential will depend on the availability of adequate habitats for all life stages. Juveniles from the upper and other subwatersheds will require the nurturing of the Lower

Subwatershed and nearshore to survive. All subwatersheds contribute vital functions necessary to recover naturally produced salmonids.

It will also be important to maintain and enhance existing habitats downstream of the dam to fully recover salmonid stocks. Areas that are currently providing critical functions should be targeted for protection. The Metzler-O'Grady reach (about RM 38 to 40) of the Middle Subwatershed is a good example of this kind of important habitat that is currently supporting naturally spawning chinook, steelhead, chum, some coho and a few sockeye and pink salmon. Other, smaller areas that are currently providing the same critical functions such as off-channel ponds or back-water sloughs should also be preserved or enhanced and noted as a high priority.

The severely modified landscape of the Duwamish and Lower Subwatersheds will make true restoration a challenge. It will be necessary to direct rehabilitation efforts through scientific research and capitalizing on significant habitat opportunities. These areas will be costly to rehabilitate and slow to respond but actions may be necessary to provide critical habitat functions for the survival of salmonids produced in upstream refugia and other areas.

INITIAL SUBWATERSHED ACTIONS

Initial Actions for each subwatershed will vary due to their respective differences in quality and quantity of existing habitats, critical habitat functions and data gaps.

The following set of initial recovery actions are not to be considered a complete suite but instead emphasize the primary method in each area as deduced from our Technical Committee's report. A more complete scientific assessment of habitats and ecological processes will occur in the years ahead, assembling the information needed for a comprehensive salmonid recovery plan in WRIA 9.

UPPER GREEN RIVER SUBWATERSHED:

RESTORE ACCESS: Efficient upstream and downstream passage of all species of adult and juvenile salmonids at Howard Hanson and Tacoma Water diversion dams. Also restore access from the Green River mainstem to tributaries.

PROTECT: critical habitats and habitat forming processes responsible for the natural production of salmonids.

MIDDLE GREEN RIVER SUBWATERSHED:

PROTECT: critical habitats and habitat forming processes responsible for the natural production of salmonids.

ENHANCE/REHABILITATE/MITIGATE: critical interrupted processes including LWD input, flow regimes, and gravel transportation. Restore access from the Green River mainstem to side channels. Enhance habitat and access within tributaries.

Note: The following downstream areas are characterized by a high degree of habitat loss and damage, extensive societal infrastructure, and a lack of information concerning basic salmonid habitat and survival requirements. Consequently, initial recovery actions should focus on filling knowledge gaps. Habitat restoration projects should be managed adaptively through scientific design, subsequent monitoring and making necessary changes.

LOWER GREEN RIVER SUBWATERSHED:

FILL DATA GAPS: through salmonid survival studies of behavior, survival needs, and habitat carrying capacity. Study results should lead to improved rehabilitation designs, clearer priorities for protection and acquisition along with an understanding of watershed natural production capability.

Rehabilitation/mitigation efforts should be based on science and managed adaptively.

PROTECT: habitat currently provides essential habitat or has reasonable potential for enhancement to keep rehabilitation options open while data gaps are being addressed.

GREEN/DUWAMISH ESTUARY SUBWATERSHED:

FILL DATA GAPS: through salmonid survival studies of the same type and for the same purposes already noted above

PROTECT: habitat currently provides essential habitat or has reasonable potential for enhancement to keep rehabilitation options open while data gaps are being addressed.

NEARSHORE:

FILL DATA GAPS: in the same manner as above

PROTECT: as noted above.

REHABILITATE/MITIGATE: critical damaged processes including sediment transport.

PRIORITY

The only over-all priority given at this time is to address the two keys to recovery noted in the opening paragraph: (1) provide efficient passage at the dams (2) initiate salmonid survival research in the lower areas.

STRATEGY SUMMARY

- Two key actions identified as early priorities for conservation of all salmonids in the Green/Duwamish watershed: (1) restoration of efficient upstream and downstream fish passage through the dams; and (2) supporting juvenile rearing in the subbasins below the dams.
- The upper subbasin has the potential to become salmonid refugia, especially for coho, steelhead, chinook, and cutthroat salmonids but must be protected and efficiently accessed.
- The severely degraded lower subbasin and estuary must provide essential ecological functions for salmonids to survive. Initial investigations should be directed at understanding and addressing the limitations these areas have on supporting salmonid juveniles from naturally spawning salmon.

2.3 SPECIFIC ACTION RECOMMENDATIONS

2.3 SPECIFIC ACTION RECOMMENDATIONS

OVERVIEW

The following recommendations focus on salmonids while recognizing that this valuable resource coexists with our human population within the various WRIA 9/Vashon Island watersheds and the Puget Sound estuary. Healthy watersheds and estuaries are vital to naturally producing salmonids and a part of the quality of life that we have come to expect. The recognition of this partnership is vital to achieve the type of support necessary for salmonid recovery. The science based recommendations below were developed by the WRIA 9 technical committee and directed towards providing healthy salmonid habitats and the ecological processes necessary for maintaining those habitats.

These non-prioritized salmonid habitat protection, data collection, and restoration actions are recommended by limiting factor and apply to the Green River mainstem as well as all tributary and nearshore areas within the geographic scope of this report. Much of the synthesis work necessary to provide detailed recommendations has not been completed at the time of printing this report, so the recommendations presented here are general and initial. More detailed prioritized recommendations will be developed during the next phase of the WRIA 9/Vashon Island/nearshore salmonid recovery planning process, which will include more comprehensive recommendations organized by categories such as; research, specific projects and policy considerations.

For the following recommendations, some or portions of them may be addressed as part of other programs (e.g.: Howard Hanson Dam Additional Storage Project, Tacoma Water Habitat Conservation Plan, etc.) under development in the basin. However, because these programs are still under development and in many cases funding has not yet been provided, the technical committee felt it was important to confirm the importance of some of these actions here. Other recommendations focus on preliminary data collection that is needed to assess some data gaps noted in this report before additional action is taken. There also are action recommendations that the technical committee sees as appropriate due to their review of existing scientific information.

WATER QUALITY

- Support the development of water quality standards that are based on all phases of salmonid life history.

- Evaluate and prioritize implementation options necessary to address water quality parameters (e.g.: dissolved oxygen, turbidity, suspended solids, heavy metals, etc.) that are factors of decline for salmonids.

- Collect continuous temperature data at several mainstem stations in the four major subwatersheds (Duwamish, Lower, Middle and Upper Green) to determine if temperature is a problem for migration, rearing or spawning of salmonids.

- Revegetate mainstem, tributary and nearshore riparian areas to assist in the reduction of water temperatures through increased shading, to improve soil stability, and to increase terrestrial insect production and input as determined necessary.

- Require erosion and sediment control Best Management Practices (BMPs) on all construction sites throughout the watershed to minimize sediment inputs into the mainstem, tributaries and nearshore areas.

- Reduce the input of detrimental metals, organic and inorganic contaminants into the Green River, WRIA 9 streams and the nearshore.

- Reduce the input of detrimental metals and organics streams and nearshore systems.

HYDROLOGY

- Investigate the impacts of surface and groundwater withdrawals on tributary stream subbasins and mainstem hydrology and evaluate the effects on salmonids.

- Manage mainstem river flows to more closely emulate the natural flow regime that promotes habitat forming processes (e.g.: creation and maintenance of side channels, pools, river meanders, etc.) and long term salmonid survival (e.g.: incubation/fry emergence, flood refugia, migration, etc.).

- Conduct a basin wide investigation of (legal and illegal) surface and ground water withdrawal.

- Perform a baseline assessment of current land use impacts to the natural stream hydrology. Studies should be carried out on a subwatershed or smaller scale to help prioritize recovery efforts. A similar assessment is needed at an appropriate scale for the nearshore.

SEDIMENT TRANSPORT

- Restore gravel and LWD to the mainstem Green River downstream of HHD. Compensate for the historic sediment deficit and provide annual quantities to mimic the estimated natural recruitment rates of sediments and LWD into the mainstem Green River downstream of HHD.

- Reduce excessive fine sediment inputs into streams.

- Minimize the removal of in-channel LWD to situations where public health and safety or significant infrastructure is threatened. Relocate, rather than remove LWD whenever feasible.

- Monitor streambed scour and deposition on a WRIA wide basis and take remedial actions where necessary.

- Determine current and historic sediment sources, distribution patterns, and budgets in the nearshore and Green-Duwamish River watershed. Compare current and historic conditions to identify the extent to which sediment transport processes require restoration.

HYDROMODIFICATION

- Reestablish and protect side channel habitat along the mainstem Green River.

- Encourage the natural channel migration of streams and rivers.

- Maintain the existing natural shorelines of the Duwamish/Green River, the nearshore of WRIA 9 and Vashon and Maury Islands.

- Remove, or set back, flood and erosion control facilities whenever feasible, to allow for the reestablishment of natural habitat producing stream and estuarine shoreline processes.

- Where levees and revetments cannot be practically removed or set back due to infrastructure considerations, maintain and repair them using design approaches that maximize the use of native vegetation and LWD.

RIPARIAN

- Establish and enhance appropriately sized, and properly functioning riparian buffers around rivers, streams, wetlands, and the nearshore. Base these buffers on scientific data and principles of landscape ecology, ecosystem and conservation biology. Where data are needed, conduct studies to determine functions and values of riparian systems.

- Conduct a detailed assessment of riparian conditions throughout the watershed to determine functional value and for evaluating potential protection, enhancement, or restoration opportunities and constraints.

- Protect riparian habitat and shorelines (streambanks and nearshore) from degradation by land use activities

- Protect and preserve areas of mid- to late-seral stage riparian habitat.

- Avoid new bank hardening projects in locations where natural bank conditions currently prevail. Retrofit existing hardened bank stabilization projects with softer, more environmentally compatible bank treatments to increase riparian functional values, where and when opportunities exist.

- Revegetate existing degraded riparian habitats with an emphasis on native plant species that will contribute future LWD to riverine and estuarine ecosystems.

- Protect riparian areas surrounding wetlands. Enhance or restore riparian areas surrounding wetlands where functions have been lost or compromised if feasible.

- Re-examine levee construction and vegetation maintenance programs, regulations and guidelines to allow propagation of native riparian vegetation.

- Protect riparian areas and extend them to include adequate protection of the stream channel migration zone (CMZ) and the nearshore.

FISH PASSAGE

- Build on the fish distribution work undertaken as a part of this report by conducting a comprehensive fish barrier and habitat assessment project to identify access barriers and the quantity and quality of habitat upstream throughout WRIA 9.

- Provide efficient fish passage and allow for natural migration rates, patterns, and timing through barriers that limit juveniles and adult salmon from reaching productive historic or rehabilitated habitats in freshwater and nearshore environments.

- Reconnect side channel habitats that have been isolated from the main channel.

- Screen all water diversions properly to avoid fish entry.

- Assess the impacts of ground and surface water withdrawals on fish passage and salmonid habitats.

- Upgrade operations and equipment at the Black River Pumping Station to promote more efficient fish passage.

- Avoid construction or addition of nearshore fill, armoring, dikes, and overwater structures that would result in a disruption of normal migration rates and patterns, or access to shallow feeding and refuge areas.

NON-NATIVE SPECIES

- Prohibit new introductions of non-native animal and terrestrial plant species that directly impact salmonids through predation, competition, and potential genetic interactions.

- Remove or control, non-native aquatic plants that adversely impact salmonid survival.

PART IV
GLOSSARY AND BIBLIOGRAPHY

1. List of Acronyms and Glossary

2. Bibliography

PART IV: GLOSSARY AND BIBLIOGRAPHY

1. List of Acronyms and Glossary

ACRONYMS USED IN WRIA 9

AWSP	Additional Water Storage Project
USACE	US Army Corps of Engineers
BRPS	Black River Pumping Station
cfs	cubic feet per second
CC	Washington Conservation Commission
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FDWRC	First Diversion Water Right Claim
HHD	Howard Hanson Dam
KC	King County
LWD	Large Woody Debris
MIT	Muckleshoot Indian Tribe
MITFD	Muckleshoot Indian Tribe Fisheries Department
MBSNF	Mount Baker Snoqualmie National Forest
MSL	Mean Sea Level
NMFS	National Marine Fisheries Service
NRCS	Natural Resource Conservation Service
NTU	Nephelometric Turbidity Unit
NWIFC	Northwest Indian Fisheries Commission
RM	River Mile
SaSI	Salmonid Stock Inventory
SASSI	Salmon and Steelhead Stock Inventory
SCS	Soil Conservation Service
SDWR	Second Diversion Water Right
SFH	State Fish Hatchery
TPU	Tacoma Public Utilities
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
USFWS	United States Fish and Wildlife Service
USFS	United States Forest Service
WAU	Watershed Administrative Unit
WDF	Washington Department of Fisheries (superceded by WDFW)
WDFW	Washington Department of Fish and Wildlife
WDOE	Washington Department of Ecology
WDNR	Washington Department of Natural Resources
WDW	Washington Department of Wildlife (superceded by WDFW)
WFPB	Washington Forest Practices Board
WRIA	Water Resources Inventory Assessment
WWTIT	Western Washington Treaty Indian Tribes

GLOSSARY

Abandoned side-channels: typically formed when a channel avulsion causes the river to move from its former route.

Adaptive management: Monitoring or assessing the progress toward meeting objectives and incorporating what is learned into future management plans.

Adfluvial: Life history strategy in which adult fish spawn and juveniles subsequently rear in streams but migrate to lakes for feeding as subadults and adults. Compare fluvial.

Aggradation: The geologic process of filling and raising the level of the streambed or floodplain by deposition of material eroded and transported from other areas.

Anadromous fish: Species that are hatched in freshwater mature in saltwater, and return to freshwater to spawn.

Aquifer: Water-bearing rock formation or other subsurface layer.

Backbar channels: overflow channels located on the apex of point bars, frequently wetted during moderately high flows, and generally do not support perennial vegetation. Multiple backbar channels may form across the top of a point bar as a result of lateral accretion of sediment during high flow events.

Baseflow: That component of streamflow derived from groundwater inflow or discharge. Can be presented in a variety of measurement units including: cubic feet per second (cfs) and inches (in).

Basin: The area of land that drains water, sediment and dissolved materials to a common point along a stream channel.

Basin flow: Portion of stream discharge derived from such natural storage sources as groundwater, large lakes, and swamps but does not include direct runoff or flow from stream regulation, water diversion, or other human activities.

Bioengineering: Combining structural, biological, and ecological concepts to construct living structures for erosion, sediment, or flood control.

Biological Diversity (biodiversity): Variety and variability among living organisms and the ecological complexes in which they occur; encompasses different ecosystems, species, and genes.

Biotic Integrity: Capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region; a system's ability to generate and maintain adaptive biotic elements through natural evolutionary processes.

Biological oxygen demand: Amount of dissolved oxygen required by decomposition of organic matter.

Braided stream: Stream that forms an interlacing network of branching and recombining channels separated by branch islands or channel bars.

Buffer: An area of intact vegetation maintained between human activities and a particular natural feature, such as a stream. The buffer reduces potential negative impacts by providing an area around the feature that is unaffected by this activity.

Carrying capacity: Maximum average number or biomass of organisms that can be sustained in a habitat over the long term. Usually refers to a particular species, but can be applied to more than one.

Channelization: Straightening the meanders of a river; often accompanied by placing riprap or concrete along banks to stabilize the system.

Channelized stream: A stream that has been straightened, runs through pipes or revetments, or is otherwise artificially altered from its natural, meandering course.

Channel Stability: Tendency of a stream channel to remain within its existing location and alignment.

Check dams: Series of small dams placed in gullies or small streams in an effort to control erosion. Commonly built during the 1900s.

Confluence: Joining.

Connectivity: Unbroken linkages in a landscape, typified by streams and riparian areas.

Critical Stock: A stock of fish experiencing production levels that are so low that permanent damage to the stock is likely or has already occurred.

Depressed Stock: A stock of fish whose production is below expected levels based on available habitat and natural variations in survival levels, but above the level where permanent damage to the stock is likely.

Debris torrent: Rapid movements of material, including sediment and woody debris, within a stream channel. Debris torrents frequently begin as debris slides on adjacent hillslopes.

Degradation: The lowering of the streambed or widening of the stream channel by erosion. The breakdown and removal of soil, rock and organic debris.

Deposition: The settlement of material out of the water column and onto the streambed.

Distributaries: Divergent channels of a stream occurring in a delta or estuary.

Diversity: Variation that occurs in plant and animal taxa (i.e., species composition), habitats, or ecosystems. See *species richness.*

Drainage Area: the area, measured in a horizontal plane, which contributes surface runoff to a stream gage.

Ecological restoration: Involves replacing lost or damaged biological elements (populations, species) and reestablishing ecological processes (dispersal, succession) at historical rates.

Ecosystem: Biological community together with the chemical and physical environment with which it interacts.

Ecosystem management: Management that integrates ecological relationships with sociopolitical values toward the general goal of protecting or returning ecosystem integrity over the long term.

Endangered Species Act: A 1973 Act of Congress that mandated that endangered and threatened species of fish, wildlife and plants be protected and restored.

Endangered Species: Means any species which is in endanger of extinction throughout all or a significant portion of its range other than a species of the Class Insecta as determined by the Secretary to constitute a pest whose protection under would provide an overwhelming and overriding risk to man.

Escapement: Those fish that have survived all fisheries and will make up a spawning population.

Estuarine: A partly enclosed coastal body of water that has free connection to open sea, and within which seawater is measurably diluted by fresh river water.

Eutrophic: Water body rich in dissolved nutrients, photosynthetically productive, and often deficient in oxygen during warm periods. Compare *oligotrophic.*

Evolutionary Significant Unit (ESU): A definition of a species used by National Marine Fisheries Service (NMFS) in administering the Endangered Species Act. An ESU is a population (or group of populations) that is reproductively isolated from other conspecific population units, and (2) represents an important component in the evolutionary legacy of the species.

Extirpation: The elimination of a species from a particular local area.

Factor of Decline: Natural and anthropogenic induced factors that contribute to the decline of salmonids. These not only include climate and ocean conditions and natural predation but also the factors that are more commonly thought to be within human control such as habitat modification, harvest, hatchery practices and introduction of non-native species.

Flood: An abrupt increase in water discharge.

Floodplain: Lowland areas that are periodically inundated by the lateral overflow of streams or rivers.

Flow regime: Characteristics of stream discharge over time. Natural flow regime is the regime that occurred historically.

Fluvial: Pertaining to streams or rivers; also, organisms that migrate between main rivers and tributaries. Compare *adfluvial.*

Freshet: a sudden increase in stream discharge that results from the rapid melting of accumulated snow.

Gabion: Wire basket filled with stones, used to stabilize streambanks, control erosion, and divert stream flow.

Genetic Diversity Unit (GDU) is defined as: A group of genetically similar stocks that is genetically distinct from other such groups. The stocks typically exhibit similar life histories and occupy ecologically, geographically and geologically similar habitats. A GDU may consist of a single stock.

Geomorphology: Study of the form and origins of surface features of the Earth.

Glides: Stream habitat having a slow, relatively shallow run of water with little or no surface turbulence.

Healthy Stock: A stock of fish experiencing production levels consistent with its available habitat and within the natural variations in survival for the stock.

Hydrograph: Chart of water levels over time.

Hydrology: Study of the properties, distribution, and effects of water on the Earth's surface, subsurface, and atmosphere.

Hydromodification: The channelization and armoring of natural banks to prevent flooding or protect stream adjacent property and structures from erosion; navigation activities (ditching, dredging and channel straightening); anthropogenic alterations in channel morphology (planform, cross-sectional area, bed and bank configuration); and anthropogenic changes in the amount of in-channel LWD.

Intermittent stream: Stream that has interrupted flow or does not flow continuously. Compare *perennial stream*.

Intraspecific interactions: Interactions within a species.

Large Woody Debris (LWD): Large woody material that has fallen to the ground or into a stream. An important part of the structural diversity of streams. LWD is also referenced to as "coarse woody debris" (CWD). Either term usually refers to pieces at least 20 inches (51 cm) in diameter.

Limiting Factor: Single factor that limits a system or population from reaching its highest potential.

Macroinvertebrates: Invertebrates large enough to be seen with the naked eye (e.g., most aquatic insects, snails, and amphipods).

Mas**s failure:** Movement of aggregates of soil, rock and vegetation down slope in response to gravity.

Mile measurement: A nautical mile.

Native: Occurring naturally in a habitat or region; not introduced by humans.

Non-Point Source Pollution: Polluted runoff from sources that cannot be defined as discrete points, such as areas of timber harvesting, surface mining, agriculture, and livestock grazing.

Outermost upland: Those lands not covered by water during an ordinary high tide.

Parr: Young trout or salmon actively feeding in freshwater; usually refers to young anadromous salmonids before they migrate to the sea. See *smolt*.

Plunge pool: Basin scoured out by vertically falling water.

Rain-on-snow events: The rapid melting of snow as a result of rainfall and warming ambient air temperatures. The combined effect of rainfall and snow melt can cause high overland stream flows resulting in severe hillslope and channel erosion.

Rearing habitat: Areas required for the successful survival to adulthood by young animals.

Recovery: The return of an ecosystem to a defined condition after a disturbance.

Redds: Nests made in gravel (particularly by salmonids); consisting of a depression that is created and the covered.
Resident fish: Fish species that complete their entire life cycle in freshwater.

Riffle: Stream habitat having a broken or choppy surface (white water), moderate or swift current, and shallow depth.

Riparian: Type of wetland transition zone between aquatic habitats and upland areas. Typically, lush vegetation along a stream or river.

Riprap: Large rocks, broken concrete, or other structure used to stabilize streambanks and other slopes.

River mouth The waters of any river or stream, including sloughs and tributaries, upstream and inside of a line projected between the outermost uplands at the mouth.

Rootwad: Exposed root system of an uprooted or washed-out tree.

SASSI: Salmon and Steelhead Stock Inventory.

SSHIAP: A salmon, steelhead, habitat inventory and assessment program directed by the Northwest Indian Fisheries Commission.

Salmonid: Fish of the family salmonidae, including salmon, trout chars, and bull trout.

Salmon: Includes all species of the family Salmonid

Sediment: Material carried in suspension by water, which will eventually settle to the bottom.

Sedimentation: The process of sediment being carried and deposited in water.

Side channel: A portion of an active channel that does not carry the bulk of stream flow. Side channels may carry water only during high flows, but are still considered part of the total active channel.

Sinuosity: Degree to which a stream channel curves or meanders laterally across the land surface.

Slope stability: The degree to which a slope resists the downward pull of gravity.

Smolt: Juvenile salmon migrating seaward; a young anadromous trout, salmon, or char undergoing physiological changes that will allow it to change from life in freshwater to life in the sea. The smolt state follows the parr state. See *parr*.

Stock: Group of fish that is genetically self-sustaining and isolated geographically or temporally during reproduction. Generally, a local population of fish. More specifically, a local population – especially that of salmon, steelhead (rainbow trout), or other anadromous fish – that originates from specific watersheds as juveniles and generally returns to its birth streams to spawn as adults.

Stream order: A classification system for streams based on the number of tributaries it has. The smallest unbranched tributary in a watershed is designated order 1. A stream formed by the confluence of 2 order 1 streams is designated as order 2. A stream formed by the confluence of 2 order 2 streams is designated order 3, and so on.

Stream reach: Section of a stream between two points.

Stream types:

Type 1: All waters within their ordinary high-water mark as inventoried in "Shorelines of the State".

Type 2: All waters not classified as Type 1, with 20 feet or more between each bank's ordinary high water mark. Type 2 waters have high use and are important from a water quality standpoint for domestic water supplies, public recreation, or fish and wildlife uses.

Type 3: Waters that have 5 or more feet between each bank's ordinary high water mark, and which have a moderate to slight use and are more moderately important from a water quality standpoint for domestic use, public recreation and fish and wildlife habitat.

Type 4: Waters that have 2 or more feet between each bank's ordinary high water mark. Their significance lies in their influence on water quality of larger water types downstream. Type 4 streams may be perennial or intermittent.

Type 5: All other waters, in natural water courses, including streams with or without a well-defined channel, areas of perennial or intermittent seepage, and natural sinks. Drainage ways having a short period of spring runoff are also considered to be Type 5.

Sub Watershed: One of the smaller watersheds that combine to form a larger watershed.

Thalweg: Portion of a stream or river with deepest water and greatest flow.

Wall-base channels: Groundwater-fed side-channels typically found at the base of a steep sideslope. Wall base channel may form as seepage that emerges from the base of the slope converges and flows toward the mainstem or they may represent former river channels that have been abandoned.

Watershed: Entire area that contributes both surface and underground water to a particular lake or river.

Watershed rehabilitation: Used primarily to indicate improvement of watershed condition or certain habitats within the watershed. Compare *watershed restoration*.

Watershed restoration: Reestablishing the structure and function of an ecosystem, including its natural diversity; a comprehensive, long-term program to return watershed health, riparian ecosystems, and fish habitats to a close approximation of their condition prior to human disturbance.

Watershed-scale approach: Consideration of the entire watershed in a project or plan.

Weir: Device across a stream to divert fish into a trap or to raise the water level or divert its flow. Also a notch or depression in a dam or other water barrier through which the flow of water is measured or regulated.

Wild Stock: A stock that is sustained by natural spawning and rearing in the natural habitat regardless of origin.

BIBLIOGRAPHY

Abbe, T.S. and D.R. Montgomery. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. Regulated Rivers: Research and Management. 12(2-3):201-221.

Agee, J.K. 1988. Successional dynamics in forest riparian zones. Pages 31-43 in K.J. Raedeke, ed. Streamside management: riparian, wildlife and forestry interaction.

Aitkin, J. K., C. K. Cook-Tabor and R. C. Wunderlich. 1996. Travel time of coho salmon and steelhead smolts emigrating through Howard Hanson Reservoir, King County, Washington. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, Washington. 57 p.

Aitkin, J.K., 1998. The importance of estuarine habitats to anadromous salmonids of the Pacific Northwest: A literature review. U.S. Fish and Wildlife Service, Aquatic Resources Division, in cooperation with the U.S. Fish and Wildlife Service, Puget Sound Program.

Alabaster, J.S. and R. Lloyd 1982. Finely divided solids. In: Water quality criteria for freshwater fish. Second Edition. Butterworth, London.

Allendorf, F.W. 1975. Genetic variability in a species possessing extensive gene duplication: Genetic interpretation of duplicate loci and examination of genetic variation in populations of rainbow trout. Ph.D. Dissertation, Univ. Washington, Seattle, WA, 98 p.

Allendorf, F.W. and F. M. Utter. 1979. Population genetics. In: W. S. Hoar, D. J. Randall and, J. R. Brett (Editors), Fish physiology. Academic Press, New York, NY. Pp. 407-454.

Ames, J. and P. Bucknell. 1981. Puget Sound River Mile Index supplement to A Catalog of Washington Streams and Salmon Utilization. Volume 1 – Puget Sound. Washington Department of Fisheries. Olympia, WA.

Amos, K. H and A. Appleby. 1999. Atlantic salmon in Washington State: a fish management perspective. September 1999, Washington Department of Fish and Wildlife, Olympia, Washington.

Anthony, K. and C. Catton 1996. Lakota Creek Basin Description.

Army Corps of Engineers. 1997. Green/Duwamish River Basin – General investigation ecosystem restoration study reconnaissance phase. January 17, 1997. 128 pp plus three Technical Appendices

Auburn, City of; City of Kent; King County; U.S. Environmental Protection Agency; U.S. Army Corps of Engineers. 1997 Draft. Mill Creek Basin, King County, Washington Aquatic resources restoration plan. Prepared by the Mill Creek SAMP Interagency Committee.

Bagley, Calrence B. 1929. History of King County, Washington. The S.J. Clarke Publishing Company. p. 711

Bayley, P. 1995. Understanding large river floodplain ecosystems. Bioscience 45(3):153-158.

Bayley, P.B. 1991. The flood pulse advantage and the restoration of river-floodplain systems. Reg. Rivers 6:75-86.

Beak Consultants, Inc. 1996. Tacoma Second Supply Project biological assessment. Prepared for Tacoma Public Utilities, Water Division. Kirkland, WA. 90 p.

Beamer, E.M. and R.A. Henderson, 1998. Juvenile salmonid use of natural and hydromodified stream bank habitat in the mainstem Skagit River, northwest Washington. Report prepared for the U.S.A.C.E., Seattle District, Seattle WA. 51 p.

Becker, C.D. 1967. The Green River hatchery, Washington: a historical and statistical review. Fisheries Research Institute Circular No. 67-1. University of Washington, Seattle WA. 37 pp.

Beechie, T., E. Beamer, and L. Wasserman. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. North American Journal of Fisheries Management. 14:797-811.

Beechie, T.J. and T.H.Sibley. 1997. Relationships between channel characteristics, woody debris and fish habitat in northwestern Washington streams. Trans. Amer. Fish. Soc. 126:217-229.

Beeson, C.E. and P.E. Doyle. 1995. Comparison of bank erosion at vegetated and non-vegetated channel bends. Water Resources Bulletin 31(6):983-990.

Bell, M.C. 1986. Fisheries handbook of engineering requirements and biological criteria. Fisheries Development and Evaluation Program, U.S. Army Corps of Engineers North Pacific Division. Portland, Oregon. 290 pp.

Benda, L., T.J. Beechie, A. Johnson and R.C. Wissmar. 1992. Morphology and evolution of salmonid habitats in a recently deglaciated river basin, Washington State, USA. Canadian Journal of Fisheries and Aquatic Sciences 49:1246-1256.

Benner, P.A. and J.R. Sedell. 1997. Upper Willamette River landscape: a historic perspective. Pages 23-47 in River quality: dynamics and restoration, A. Laenen and D.A. Dunnette, Eds., Lewis Publishers, New York.

Benoit, Paul, 1979 The Man-Induced Topographic Chande of Seattle's Elliott Bay Shoreline from 1852 to 1930 as an Early Form of Coastal Resource Use and Management Masters Thesis, University of Washington.

Bergman, H.L. and E.J. Dorward-King, eds. 1997. Reassessment of metals criteria for aquatic life protection: priorities for research and implementation. SETAC Pellston Workshop on Reassessment of Metals Criteria for Aquatic Life Protection: 1996 Feb 10-14. Pensacola, FL. SETAC Press. 114 pp.

Beschta, R.L.; Bilby, R.E.; Brown, L.B. and Hofstra, T.D. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. P. 191-232 E.O. Salo and T.W. Cundy, eds., Streamside Management: Forestry and Fishery Interactions. Contribution number 57, College of Forest Resources, University of Washington, Seattle, Washington.

Bestari, K.T.J, R.D. Robinson, K.R. Solomon, T.S. Steele, K.D. Day, and P.K. Sibley. 1998. Distribution and composition of polycyclic aromatic hydrocarbons within experimental microcosms treated with liquid creosote. Environmental Toxicology and Chemistry 17:2359-2368.

Bilby, R. 1984. Characteristics and frequency of cool-water areas in a western Washington stream. Journal of Freshwater Ecology 2(6):593-602.

Bilby, R.E. and G.E. Likens. 1980. Importance of organic debris dams in the structure and function of ecosystems. Ecology 61:1107-1113.

Bjornn, T.C. and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. In: Meehan, W.R. ed., Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19:83-138. Bethesda, MD.

Blomberg, G., C. Simenstad, and P. Hickey. 1988. Changes in Duwamish River estuary habitat over the past 125 years. Pages 437-454 *in* Proceedings. First annual meeting on Puget Sound research. Volume 2. Prepared by the Puget Sound water quality authority. Seattle, WA.

Blomberg, George. Biologist, Port of Tacoma. Personal communication. E-mail to Sue Madsen, R2 Resource Consultants, 7 October, 1999.

Boehm, W. 1999. General site survey and level II stream survey report for lower Newaukum Creek. Submitted to King County Department of Transportation. Prepared by William Boehm, King County Department of Natural Resources, Wastewater Treatment Division, Surface Water engineering and Environmental Services. Seattle, Washington.

Booth, D. B. and C. R. Jackson. 1997. Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the units of mitigation. Journal of the American Water Resources Association 33:1077-1090.

Booth, D.B. 1990. Stream channel incision following drainage basin urbanization. Water Resources Bulletin, 26(3):407-417.

Booth, D.B., A. Stonkus, M. Lampard, S. Kaufman, R. Schaefer, J. Burkey, W. Kara and T. Bennett. 1994. Enhanced reconnaissance of the eastern tributaries of the lower Green River basin: data, analyses, and management recommendations. King County Basin Planning Program, Surface Water Management Division, Department of Public Works, Seattle, WA. 57 p. plus Appendices.

Booth, Derek. September 2000. Forest Cover, Impervious Surface area, and the Mitigation of Urbanization Impacts in King County. Center for Urban Water Resources Management, University of Washington,

Bortelson, G.C., M.J. Chrzastowski and A.K. Helgerson. 1980. Historical changes of shoreline and wetland at eleven major deltas in the Puget Sound Region, Washington. U.S.G.S. Hydrologic Investigations Atlas HA-617.

Brennan, J. and H. Culverwell. In press. Marine Riparian: An assessment of riparian functions in marine ecosystems. Working Draft. King County Department of Natural Resources, Seattle, Washington.

Broadhurst, Ginny. 1988. Puget Sound Nearshore Habitat Regulatory Perspective: A Review of Issues and Obstacles. Puget Sound Water Quality Action Team: Prepared for Puget Sound/Georgia Basin International Task Force. Olympia, WA

Budd, W.W.; Cohen, P.L.; Saunders, P.R. and Steiner, F.R. 1987. Stream corridor management Pacific Northwest: determination of stream-corridor widths. Environmental Management 11:587-597.

Burkey, J. 2000. Jeff Burkey, Hydrologist (King County) personnel communication to John Kerwin, Regional Technical Coordinator (Washington Conservation Commission).

Burroughs, E.R., Jr and B.R. Thomas. 1977. Declining root strength in Douglas-fir after felling as a factor in slope stability. U.S.D.A. Forest Service Research Paper INT-190. Ogden, Utah. 27 p.

Bury, R.B., P.S. Corn, K.B. Aubry, F.F. Gilbert and L.L.C Jones. 1991. Aquatic amphibian communities in Oregon and Washington. Pages 353-362 *in* L.F. Ruggierio, K.B. Aubry, A.B. Carey and M.H. Huff Eds. Wildlife and vegetation of unmanaged Douglas-fir forests. U.S. Forest Service Gen. Tech. Rep. PNW-285. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Busack, C. and J.B. Shaklee. 1995. Genetic diversity units and major ancestral lineages of salmonid fishes in Washington. Washington Department of Fish. Olympia, WA.

Busby, P.J., T.C. Wainwright, G.J. Bryant, L.J. Lierheimer, R.S. Waples, F.W. Waknitz, and I. V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Oregon, and California. U.S. Department of Commerce, NOAA, Seattle. Technical Memorandum NMFS-NWFSC-27. U.S. Department of Commerce, NOAA, Seattle.

Cada, G. F., M. D. Deacon, S. V. Mitz, and M. S. Bevelhimer. 1994. Review of the information pertaining to the effect of water velocity on the survival of juvenile salmon and steelhead in the Columbia River basin. Prepared for Northwest Power Planning Council. February 1994. Portland, Oregon. 71 p.

Cagney, P. 2000. Patrick Cagney (US Army Corps of Engineers) personal communication to John Kerwin (Washington Conservation Commission).

Caldwell, B. and S. Hirschey. 1989. Green River fish habitat analysis using the Instream Flow Incremental Methodology. IFIM Technical Bulletin 89-35. Water Resources Program, Washington State Department of Ecology. Olympia, WA. 149 p.

Caldwell, J. E. 1994. Green River temperature investigation 1992. Report prepared for the Muckleshoot Tribe, Fisheries Department, Auburn, WA. May.

Canning, D.J., S.G. Herman, and G.B. Shea. 1979. Terminal 107 environmental studies, wildlife study. Prepared for the Port of Seattle. Oceanographic Institute of Washington and Northwest Environmental Consultants. Seattle, Washington.

Carlson, C.V. 1994. Big Soos Creek low flow trend and water right analysis. Muckleshoot Indian Tribe, Fisheries Department. Auburn, Washington.

Cassidy, K. M., M. R. Smith, C. E. Grue, K. M. Dvornich, J. E. Cassidy, K. R. McAllistr, and R. E. Johnson. 1997. Gap Analysis of Washington State: an evaluation of the protection of biodiversity. Volume 5 in Washington State Gap Analysis – final repot (K. M. Cassidy, C. E. Grue, M. R. Smith, and K. M. Dvornich, eds.). Washington Cooperative Fish and Wildlife Research Unit, University of Washington, Seattle.

Castelle, A.J., A.W. Johnson and C. Conolly. 1994. Wetland and stream buffer requirements – a review. Journal of Environmental Quality 23:878-882.

Cavalli-Sforza, L.L., and A.W. Edwards. 1967. Phylogenetic analysis: Models and estimation procedures. Am. J. Human Genet. 19:233-257.

Cederholm, C.J. and W.J. Scarlett. 1982. Seasonal immigration of juvenile salmonids into four small tributaries of the Clearwater River, Washington 1972-1982. Pages 98-110 in E.L. Brannon and E.O. Salo Eds., Proceedings of the salmon and trout migratory behavior symposium. University of Washington School of Fisheries, Seattle, WA.

Cederholm, C.J., D.H. Johnson, R.E. Bilby, L.G. Dominguez, A.M. Garrett, W.H. Graeber, E.L. Greda, M.D. Kunze, B.G. Margot, J.F. Palmisano, R.W. Plotnikoff, W.G. Pearcy, C.A. Simenstad, and P.C. Trotter, 2000. Pacific Salmon and Wildlife - Ecological Contexts, Relationships, and Implications for Management. Special Edition Technical Report, Prepared for D.H. Johnson and T.A. O'Neil (Manag. Dirs.), Wildlife-Habitat Relationships in Oregon and Washington. Washington Department of Fish and Wildlife, Olympia.

Cederholm, C.J., R.E. Bilby, P.A. Bisson, T.W. Bumstead, B.R. Fransen, W.J. Scarlett and J.W. Ward. 1997. Response of Juvenile Coho Salmon and Steelhead to Placement of Large Woody Debris in a Coastal Washington Stream. North American Journal of Fisheries Management 17:947-963.

Chamblin, M. 2000. Personal communication with Mike Chamblin, Biologist, Washington Department of Fish and Wildlife. E-mail to S. Madsen, R2 Resource Consultants, 3 February 2000.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Trans. Amer. Fish. Soc. 117:1-21.

Coccoli, H. and A. Morgan. 1997. Green/Duwamish basin, p. 40-45 in Bishop, S and A. Morgan Eds., Critical habitat issues by basin for natural chinook stocks in the coastal and Puget Sound areas of Washington state. Northwest Indian Fisheries Commission, Olympia WA.

Coccoli., H.A. 1996. Effects of springtime flow alteration on side channel habitat in the Green River. M.S. Thesis. University of Washington, Seattle, WA. 77 p.

Cohen, A., et al., 1998. Puget Sound Expedition: A rapid assessment survey of non-indigenous species in the shallow waters of Puget Sound. Prepared for the Washington State Department of Natural Resources, Olympia, WA, and the United States Fish and Wildlife Service, Lacey, WA.

Coho, C. 1996. Section 4B, Surface Erosion Module in Plum Creek. 1996. Lester Watershed Analysis. Watershed Analysis prepared for the Washington Department of Natural Resources by the Plum Creek Timber Company. Washington Department of Natural Resources, Olympia Washington.

Coho, C. 1997. Section 4B, Surface Erosion Module in Plum Creek. 1997. Upper Green Sunday Watershed Analysis. Draft Watershed Analysis prepared for the Washington Department of Natural Resources by the Plum Creek Timber Company.

Coho, C. S. 1993. Dam-break floods in low-order mountain channels of the Pacific Northwest. Unpublished Masters Thesis. Department of Civil Engineering, University of Washington.

Cordell, Jeff. 2000. Wetland Ecosystems Team, School of Fisheries, University of Washington, Seattle. Personal communication.

Cordone, A.J. and D.W. Kelly. 1961. The influences of inorganic sediment on the aquatic life of streams. Cal. Fish and Game 47:189-228.

Cropp, T. 1999, 2000. Personal Communication from Tom Cropp (Area Fish Management Biologist) WDFW to John Kerwin (Regional Technical Coordinator (Washington Conservation Commission).

Cropp, T. 1999. Personal communication: Telephone conversation between Tom Cropp, WDFW Fisheries Biologist and Sue Madsen (R2 Resource Consultants). June 7 1999.

Cropp, T. 1999. Tom Cropp (Washington Department of Fish and Wildlife, Fisheries Biologist) personal communication to John Kerwin (Washington Conservation Commission).

Cropp, Tom. 2000. Region 4, WDFW, Mill Creek, Washington. Personal Communication.

Culhane, T. 1995. Watershed Assessment: Water Resources Inventory Area 9. Green-Duwamish Watershed. Washington Department of Ecology Open File Report 95-01, Bellevue, Washington. 52 pp.

Cupp, E. and J. Metzler. 1996. Section 4E, Channel Condition Module in Plum Creek. 1996. Lester Watershed Analysis. Watershed Analysis prepared for the Washington Department of Natural Resources by the Plum Creek Timber Company. Washington Department of Natural Resources, Olympia Washington.

Cutler, J. 1999. Fisheries Biologist, Northwest Indian Fisheries Commission, Personal communication with J. Kerwin (Washington State Conservation Commission). 20 July 1999.

Cutler, J. 2000. Personal communication with Jennifer Cutler, habitat specialist, Northwest Indian Fisheries Commission. Letter to S. Madsen, R2 Resource Consultants. 9 February 2000.

Davis, S. et al. 1992a. Longfellow Creek Watershed Characterization Report. Prepared for the City of Seattle Drainage and Wastewater Utility and the Longfellow Creek Watershed Management Committee.

Davis, S. et al. 1992b. Longfellow Creek Watershed Action Plan for the Control of Nonpoint Source Water Pollution. Prepared for the City of Seattle Drainage and Wastewater Utility and the Longfellow Creek Watershed Management Committee.

Dean, Tom. 2000. People for Puget Sound, Seattle, Washington. Personal Communication.

Dethier, M.N. 1990. A marine and estuarine habitat classification system for Washington State. Washington Natural Heritage Program, Washington State Department of Natural Resources, Olympia.

Dill, L.M. and T.G. Northcote. 1970. Effects of gravel size, egg depth, and egg density on intergravel movement and emergence of coho alevins. J.Fish. Res. Board Can. 27:1191-1199.

Dilley, S. J., and R. C. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Project, Green River, Washington, 1991. Prepared by the U.S. Fish and Wildlife Service Western Washington Fishery Resource Office, Olympia, Washington. 69 p.

Dilley, S. J., and R. C. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Project, Green River, Washington, 1992. Prepared by the U.S. Fish and Wildlife Service Western Washington Fishery Resource Office, Olympia, Washington. 73 p.

Dolloff, C.A. 1987. Seasonal population characteristics and habitat use by juvenile coho salmon in a small southeast Alaska stream. Trans. Amer. Fish. Soc. 116:829-838.

Dorn, P. 1999, 2000. Paul Dorn Suquamish Indian Tribal ESA Coordinator to John Kerwin Washington Conservation Commission.

Doughty, K. 1996. Section D *in* Plum Creek Timber Company, L.P. (Plum Creek). Lester Watershed Analysis. Report prepared by Plum Creek for Washington Department of Natural Resources.

Dunne, T. and W.E. Dietrich. 1978. Geomorphology and hydrology of the Green River. Appendix A in: Jones and Jeones, eds., A River of Green. Report to King County. P. A1-A33.

Dunne, T.E. and L.B. Leopold. 1978. Water in environmental planning. W.H. Freeman and Company, New York. 818 p.

Duwamish and Green River Joint Survey Board (DGRJSB). 1954. Development Plan for Duwamish and Lower Green River. Prepared for the City of Seattle, King County, and the Port of Seattle.

Ehlert, H. 1997. Section D *in* Plum Creek Timber Company, L.P. (Plum Creek). Upper Green/Sunday Watershed Analysis. Report prepared by Plum Creek for Washington Department of Natural Resources. DRAFT

Elliott, S.T. 1986. Reduction of Dolly Varden population and macrobenthos after removal of logging debris. Trans. Am. Fish. Soc. 115:392-400.

Entranco, Taylor Associates and Envirovision. 1997. Riverton Stormwater Quality Management Plan: Water quality, stream habitat, and flood control. Consultant report prepared for the City of Tukwila. Tukwila Department of Public Works, Tukwila, WA. 64 p. plus Appendices.

European Inland Fisheries Advisories Commission 1964. Water quality criteria for European freshwater fish. Report on finely divided solids and inland fisheries.. Technical Paper 1.

Evans, D.H. 1987. The fish gill: site of action and model for toxic effects of environmental pollutants. Environ. Health Perspect. 71:47-58.

Fausch, K.D. and T.G. Northcote. 1992. Large woody debris and salmon habitat in a small coastal British Columbia stream. Can. J. Fish. Aquat. Sci. 49:682-693.

Finney, D. 2000. Don Finney, King County Fisheries Biologist, personnel communication to John Kerwin (Washington Conservation Commission).

Finney, D. 2000. Personal communication with Don Finney, Fisheries Biologist, King County Department of Developmental Services. Telephone conversation with S. Madsen, R2 Resource Consultants. 1 February 2000.

Fore, L.S., J.R. Karr, and R.W. Wisseman. 1997. A benthic index of biotic integrity for streams in the Pacific Northwest. Journal of the North American Benthological Society.

Forest Ecosystem Management Assessment Team. 1993. Forest ecosystem management: an ecological, economic, and social assessment. USDA Forest Service and USDI Bureau of Land Management. 9 chapters.

Foster, M.S., A.P. DeVogelaere, C. Harlod, J.S. Pearse, and A.B. Thum. 1986. Causes of spatial and temporal patterns in rocky intertidal communities of central and northern California. Volume 2 of 2. Outer Continental Shelf Study MMS 85-0049. U.S. Department of Interior, Minerals Management Service. Contract No. 14-12-0001-30057.

Foster, R.F. 1943. Sources of pollution in the Duwamish-Green River drainage area. Washington State Department of Ecology, Pollution Control Commission, Olympia, WA.

Fox, M. 1996. Section 4F, Fish Habitat Module *in* Plum Creek. 1996. Lester Watershed Analysis. Watershed Analysis prepared for the Washington Department of Natural Resources by the Plum Creek Timber Company. Washington Department of Natural Resources, Olympia Washington.

Fox, M. and G. Watson. 1997. Fish Habitat; Section 4F Upper Green/Sunday Watershed Analysis. Prepared by Plum Creek for Washington Department of Natural Resources. 52 p. DRAFT

Fox, M. J., J. Sikes, B. Footen. 1997. Stream Typing Verification: An Analysis of Washington Department of Natural Resources Stream Classification System. U.S. Fish and Wildlife Grant Report Cooperative Agreement No. 14-480001-95736, Jobs in the Woods. Muckleshoot Indian Tribe Fisheries Department, Auburn Washington.

Franklin, J.F. and C.T. Dyrness. 1973. Natural vegetation of Oregon and Washington. U.S. Forest Service Gen. Tech. Rep. PNW-8. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Franklin, J.F. K. Cromack Jr., W. Denison, A. McKee, C. Maser, J.R. Sedell, F.J. Swanson and G. Juday. 1981. Ecological characteristics of old-growth Douglas-fir forests. U.S. Forest Service Gen. Tech. Rep. PNW-118. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Franklin, J.F., and R.T. Forman. 1987. Creating landscape patterns by forest cutting: ecological consequences and principals. Landscape Ecology 1:5-18.

Fransen, B.R., P.A. Bisson, J.W. Ward, and R.E. Bilby. 1993 Physical and biological constraints on summer rearing of juvenile coho salmon (*Onchorhynchus kisutch*) in small western Washington streams. Pages 271-288 in Proceedings of the coho salmon workshop. Sponsored by the Association of Professional Biologists of British Columbia and the North Pacific International Chapter of the American Fisheries Society, Nanaimo, British Columbia

Fuerstenberg, et. al. 1999. “Draft Ecological Conditions and Limitations to Salmonid Diversity in the Green River, Washington, USA. Structure, Function, and Process in River Ecology.” Unpublished report. King County Department of Natural Resources. Seattle, Washington.

Fuerstenberg, R.R., K. Nelson, and R. Blomquist. 1996. Ecological conditions and limitations to salmonid diversity in the Green River Washington, USA: storage, function and process in river ecology. Draft. King County Department of Natural Resources, Surface Water Management Division, Seattle, WA. 31 p.

Gecy, J.L. and M.V. Wilson. 1990. Initial establishment of riparian vegetation after disturbance by debris flows in Oregon. Am. Midl. Nat. 123(2):282-291.

Geist, Dick. 2000. Washington Department of Fish and Wildlife, Seattle, Washington. Personal Communication.

Gibbons, D.R. and E.O. Salo. 1973. Annotated bibliography of the effects of logging on fish of the western United States and Canada. U.S. Forest Service Gen. Tech. Rep. PNW-10. 145 pp.

Goetz, F. 2000. Personal communication with Fred Goetz, Fisheries Biologist, U.S. Army Corps of Engineers, Seattle Division. E-mail to Tom Nelson, King County. 9 February 2000.

Goetz, F. 1994. Personnel communication to Beak Consultants, Inc. Bull trout capture in 1956.

Goldberg, J.S., C. Thrush, C. Paston, C. Woelfel, T. Millikin, 1992. Longfellow Creek – Water Quality Assessment. Report to Drainage and Wastewater Utility. January 1992. 150 pp.

Goldstein, L. S. 1982. Newaukum Creek stream resource inventory technical report. Report by La Terre Environmental Consultants to Metro Water Quality Division, Technical report ER-82-8, Seattle, Washington.47 p.

Goldstein, L. S. 1982. Soos Creek stream resource inventory. Report by La Terre Environmental Consultants to Metro Water Quality Division, Technical report WR-82-7, Seattle, Washington.

Good, James W. and Ridlington, Sandra S. 1992. Coastal Natural Hazards: Science, Engineering, and Public Policy. Oregon Sea Grant, Oregon State University. Corvallis, OR.

Good, James W., John W. Weber, James W. Charland, John V. Olson, Kelly A. Chapin. 1998. National Coastal Zone Management Effectiveness Study: Protecting Estuaries and Coastal Wetlands. Oregon Sea Grant and Marine Resource Management Program, OSU. Corvallis, OR.

Gore, J.A. 1985. The restoration of rivers and streams. Butterworth Publishers, Boston MA.

Gregory, S.V., F. J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. Bioscience 42:540-551.

Grette, G.B., and E.O. Salo. 1986. The status of anadromous fishes of the Green/Duwamish River system. Prepared for the US Army Corps of Engineers, Seattle District, by Evans-Hamilton, Inc., Seattle, Washington.

Gustafson, R.G., T.C. Wainwright, G.A. Winans, F.W. Waknitz, L.T. Parker, and R.S. Waples. 1997. Status review of sockeye salmon from Washington and Oregon. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-33, 282 p.

Hadley, Carl. 2000. Senior fisheries biologist, Associated Earth Sciences Inc. Personal communication, e-mail to S. Madsen, R2 Resource Consultants 10 February, 2000.

Hamelink, J.L., P.F. Landrum, H.L. Bergman, and W.H. Benson Eds. 1994. Bioavailability: Physical, Chemical, and Biological Interactions. Proceedings of a workshop held in

Pellston, Michigan, in 1992, sponsored by the Society of Environmental Toxicology and Chemistry. CRC Press, Boca Raton, Florida.

Hanson, H.A. 1957. More land for industry. The story of flood control in the Green River Valley. Pacific Northwest Quarterly. January 1957:1-7.

Harmon, M.E.; Franklin, J.F.; Swanson, F.J.; Sollins, P.; Gregory, S.V.; Lattin, J.D.; Anderson, N.H.; Cline, S.P.; Aumen, N.G.; et al. 1986. Ecology of coarse woody debris temperate ecosystems. Advances Ecological Research 15:133-302.

Harper-Owes. 1983. Water quality assessment of the Duwamish estuary, Washington. Prepared for Municipality of Metropolitan Seattle (METRO), Seattle, Washington.

Harr, R.D., 1981. Some characteristics and consequences of snowmelt during rainfall in western Oregon. Journal of Hydrology 53:277-304.

Harr, R.D., W.C. Harper, J.T. Krygier and F.S. Hseih. 1975. Changes in storm hydrographs after road building and clearcutting in the Oregon Coast Range. Water Resourc. Res. 11(3):436-444.

Harris, L.D. The fragmented forest: island biogeography theory and the preservation of biotic diversity. University of Chicago Press, Chicago Illinois. 211 p.

Harza. 1995. Final Report: Comprehensive fisheries assessment of the Mill Creek, Garrison Creek and Springbrook system. Consultant report prepared for the City of Kent, Environmental Engineering. Kent, Washington. 114. pp. + Appendices.

Haupt, H.F., 1979. Local climate and hydrologic consequences of creating openings in climax timber of north Idaho. U.S. Forest Service Research Paper INT-223, Ogden, Utah.

Heiser, D.W. and E.L. Finn, Jr., 1970. Observations of juvenile chum and pink salmon in marina and bulkheaded areas. Washington Department of Fisheries, Management and Research Division.

Heller, R. et al. 1987. Reconnaissance Report No. 12 Miller Creek Basin. Natural Resources and Parks Division and Surface Water Management Division. King County WA. 9 pps. plus appendices.

Heller, R. et al. 1987. Reconnaissance Report No. 23 Salmon Creek Basin. Natural Resources and Parks Division and Surface Water Management Division. King County WA. 11 pps.

Hershberger, W.K. and R. N. Iwamoto. Undated. Genetics Manual and Guidelines for the pacific Salmon Hatcheries of Washington. University of Washington, Seattle.

Hickey, P. 1999. Paul Hickey (Tacoma Public Utilities, Tacoma Water) personal communication to John Kerwin (Washington Conservation Commission).

Hickey, P. 1999. Personal communication with Paul Hickey, Biologist, Tacoma Public Utilities. Conversation with S. Madsen, R2 Resource Consultants at WRIA 9 FODS meeting, 5 May 1999.

Hickey, P. 2000a. Personal communication with Paul Hickey, Biologist, Tacoma Public Utilities. E-mail to S. Madsen, R2 Resource Consultants, 9 March 2000.

Hickey, P. 2000b. Personal communication with Paul Hickey, Biologist, Tacoma Public Utilities. Conversation with S. Madsen, R2 Resource Consultants at WRIA 9 FODS meeting, 1 May 2000.

Hickey, P. 2000c. Personal communication with Paul Hickey, Biologist, Tacoma Public Utilities. Telephone conversation with S. Madsen, R2 Resource Consultants, 18 May 2000.

Hicks, M. 2000a. Preliminary review draft discussion paper: Evaluating standards for protecting aquatic life in Washington’s surface water quality standards. Temperature criteria.

Washington State Department of Ecology. Water Quality Program. Olympia, Washington.
Hicks, M. 2000b. Preliminary review draft discussion paper: Evaluating criteria for the protection of aquatic life in Washington's surface water quality standards. Dissolved oxygen. Washington State Department of Ecology. Water Quality Program. Olympia, Washington.
Higgins, Wade. 2000. Wade Higgins personal observation related to John Kerwin.
Hilgert, P. 1999. Senior fisheries biologist, R2 Resource Consultants. Personal communication with S. Madsen (R2). 31 March, 1999.
Hillis, D.M., C. Mortiz and B.K. Mable (eds.). 1996. Molecular systematics. Second edition. Sinauer Assoc., Sunderland, MA.
Hoffman, R.S., P.D. Capel, and S.J. Larson. 2000. Comparison of pesticides in eight U.S. urban streams. Environmental Toxicology and Chemistry 19(9):2249-2258.
Hollis, G.E. 1975. The effects of urbanization on floods of different recurrence intervals. Water Resources Research. 11:431-435.
Jeanes, E.D. and P. J. Hilgert. 2000. Juvenile salmonid use of lateral stream habitats in the Middle Green River, Washington. Report prepared for U.S. Army Corps of Engineers, Seattle District and City of Tacoma Public Utilities, Tacoma WA.
Johannessen, J., 1992. Net Shore-Drift of San Juan, and parts of Jefferson, Island, and Snohomish Counties, Washington. Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia.
Johnson, A.W. and Ryba, D.M. 1992. A literature review of recommended buffer widths to maintain various functions of stream riparian areas. Prepared King County Surface Water Management Division. 29pp.
Johnson, D. 2000. Doreen Johnson, local resident in Coal and Deep Creek subbasins. Memorandum to John Kerwin (Regional Technical Representative) Washington Conservation Commission dated October 31, 2000.
Johnson, O.W., W.S. Grant, R.G. Kope, K. Neely, F.W. Waknitz, and R.S. Waples. 1997. Status review of chum salmon from Washington, Oregon and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-32, 280 p.
Johnson, R. E. and K. M. Cassidy. 1997. Mammals of Washington State: location data and predicted distribution. Volume 3 in Washington State Gap Analysis – final repot (K. M. Cassidy, C. E. Grue, M. R. Smith, and K. M. Dvornich, eds.). Washington Cooperative Fish and Wildlife Research Unit, University of Washington, Seattle.
Johnson, R., 1999. Memo: Miller Creek Estuary Restoration, King County Department of Natural Resources.
Jones, S.J. 2000. Stream Assessment of Unnamed Tributary of Puget Sound Lot 3, Block 33, Buenna Addition 268XX 2nd Ave. SW Federal Way, Washington. Prepared for Riverstone Homes, Inc. January 7, 2000. 9 pps.
Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Pages 110-127 in D.P. Dodge, Ed. Proc. of the international large river symposium, Honey Harbour, Ontario, Sept. 14-21, 1986. Can. Spec. Publ., Fish. Aquat. Sci. 106-110-127.
Karr, J. R. 1991. Biological integrity: a long-neglected aspect of water resource management. Ecological Application 1(1):66-84.

Kellerhals, R.M. and M. Church, 1989. The morphology of large rivers: characterization and management. Pages 31-48 in D.P. Dodge, Ed.,Proceedings of the international large river symposium. Canadian Special Publication Fisheries and Aquatic Sciences 106.

Kendra, Will. 1989. Water Quality in Fauntleroy Creek and Cove During the Summer of 1988. Washington Department of Ecology. Olympia, WA.

Kent, City of. 1991. Water Quality Program 1992-1996. Kent, WA.

Kent, City of. 1995. Comprehensive Fisheries Assessment or the Mill Creek, Garrision Creek, and Springbrook System. Kent, WA.

Kerwin, J. 2000. Personal communication with John Kerwin, Regional Technical Coordinator, Washington Conservation Commission. E-mail to S. Madsen, R2 Resource Consultants, 19 April 2000.

Kerwin, John. 2000. Personal Observation. John Kerwin, Regional Technical Coordinator Washington Conservation Commission.

Kimbel, M.. 1998. Future Brood Development. Northwest Indian Fish Commission, Washington Department of Fish and Wildlife and U.S. Fish and Wildlife Service, Olympia, Washington, Olympia.

Kimpo, Angela and K. Maher. 1997. Joe’s Creek. Basin summary.

King County 1993. King County Flood Hazard Reduction Plan. 243 pp.

King County 1999. Information downloaded from King County Web-site, 13 April 1999. (http://splash.metrokc.gov/wlr/BASINS/lowgreen.htm).

King County 1999. Locations of riverbank stabilization and restoration projects on the Green River. Http://splash.metrokc.gov//wlr/flood/Boaters/Green/green.html. 10/21/99 7:49 a.m.

King County Basin Reconnaissance, Volume II. 1990. King County Department of Public Works, Surface Water Management.

King County Countywide Planning Policies Benchmark Program (KCCPPBP). 2000. Affordable Housing Indicators.

King County Department of Development and Environmental Services (KCDDES). 1994. 1994 King County Comprehensive Plan.

King County Department of Development and Environmental Services (KCDDES). 1994B. 1994 King County Comprehensive Plan: Technical Appendices Volume 2.

King County Office of Regional Policy and Planning. 2000. The 2000 Annual Growth Report.

King County Office of Regional Policy and Planning. 2000. The 2000 Annual Growth Report.

King County Planning Commission (KCPC). 1957. Duwamish Valley Study.

King County Planning Department (KCPD). 1964. 1964 King County Comprehensive Plan.

King County Planning Department (KCPD). 1985. 1985 King County Comprehensive Plan.

King County Planning Division. 1978. A river of green. Prepared by King County planning Division and Jones & Jones. Seattle, WA. 156 p.

King County Planning Division. 1978. Technical appendices to the river of green. Prepared by King County Planning Division and Jones & Jones. Seattle, WA. 119 p.

King County Surface Water Management Division. 1989 Soos Creek basin plan and draft environmental impact statement. King County Surface Water Management Division, Seattle, Washington.

King County. 1975. Vashon-Maury Island Physical Characteristics and Shoreline Inventory. Department of Community and Environmental Development, Land Use Management Division.

King County. 1986. Mill Creek Basin Study. Green River Basin Program. 47 p.
King County. 1986. Mill Creek Basin Study. Green River Basin Program. 47 p.
King County. 1987. Basin Reconnaissance report No. 14: Black River basin. Natural Resources and Parks Division and Surface Water Management Division, Seattle, WA.

King County. 1989. Green-Duwamish Watershed Nonpoint Action Plan – Concurrence Draft. Department of Parks, Planning and Resources, Seattle, WA.

King County. 1989. Soos Creek Basin Plan and Draft Environmental Impact Statement. Department of Public Works, Seattle WA. 272 p.

King County. 1990a. King County Wetlands Inventory, Volume III, South. King County Department of Parks, Resources and Inventory. Seattle, Washington.

King County. 1990b. King County Sensitive Areas Map Portfolio.

King County. 1991. King County Surface Water Management, Executive Proposed Basin Plan: Hylebos Creek and Lower Puget Sound.

King County. 1992. Longfellow Creek Watershed Characterization Background Report, Report to Longfellow Creek Watershed Management Committee, Seattle Drainage and Wastewater Utility and WA Dept. of Ecology. 187 pp.

King County. 1993. Mill Creek Water Quality Management Plan. King County Surface Water Management. Seattle, WA.

King County. 1994. South 96th Street Water Quality Engineering Report, Volume 1. Prepared by Herrera Environmental Consultants, Inc. for King County Surface Water Management Division.

King County. 1995. Draft Vashon-Maury Island Ground Water Management Plan: Area Characterization.

King County. 1995a. Draft Hamm Creek Resource Management Plan. Prepared for the Habitat and Water Quality Sub-Committee, Duwamish Coalition by King County Surface Water Management Division.

King County. 1997. Des Moines Creek Basin Plan. Prepared by the Des Moines Creek Basin Committee.

King County. 1998. Vashon-Maury Island Ground Water Management Plan – Final. King County Department of Natural Resources, Seattle, WA.

King County. 1998. Vashon-Maury Island Ground Water Management Plan Supplement: Area Characterization. King County Department of Natural Resources, Seattle, WA.

King County. 1999. Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay. Prepared by Parametrix, Inc. and King County Department of Natural Resources. Seattle, WA.

King County. 2000. Waterweeds: A Report on Volunteer Survey Results for Fifteen King County Lakes. Prepared by Sharon Walton, Senior Limnologist, King County Water and Lands Resource Division. Seattle, WA.

Knighton, D. 1984. Fluvial forms and processes. Edward Arnold. New York. 218 p.

Knudsen, E.E. and S.J. Dilley. 1987. Effects of riprap bank reinforcement on juvenile salmonids in four western Washington streams. North American Journal of Fisheries Management 7:351-356.

Knutsen, K. L. and V.L. Naef. 1997. Management recommendations for Washington's priority habitats: riparian. Washington Department of Fish and Wildlife, Olympia, Washington. 181 pp.

Kozel, S.J., W.A. Hubert, and M.G. Parsons. 1987. Habitat features and trout abundance relative to gradient in some Wyoming streams. Northwest Science 63:175-182.

Kramer, Chin & Mayo, Inc. (KCM). 1986a. Fostoria Creek basin drainage study. Consultant report prepared for the City of Tukwila. Tukwila Department of Public Works, Tukwila, WA. 38 p. plus Appendices.

Kramer, Chin & Mayo, Inc. (KCM). 1986b. Gilliam Creek basin drainage study. Consultant report prepared for the City of Tukwila. Tukwila Department of Public Works, Tukwila, WA. 48 p. plus Appendices.

Kramer, Chin and Mayo. 1977. Longfellow Creek Rehabilitation Study. Done for the City of Seattle, Engineering Department.

Krug, 1949. Green and Duwamish rivers, and Duwamish Waterway, Seattle Harbor, Wash. Letter from the secretary of the army transmitting a letter from the U.S. Army Chief Engineer on a preliminary examination and survey of the Green and Duwamish rivers. 81st Congress 1st Session. House of Representatives Document No. 271.

Leary, R. F., F. W. Allendorf, and K.L. Knudsen. 1983. Consistently high meristic counts in natural hybrids between brook trout and bull trout. Systematic Zoology 32:369-376.

Leary, R. F., F. W. Allendorf, and S.H. Forbes. 1991. Conservation genetics of bull trout in the Columbia and Klamath River drainages. Wild Trout and Salmon Genetics Laboratory Report 91/2. 32 p.

Ledgerwood, R. D., E. M. Dawley, L. G. Gilbreath, L. T. Parker, B. P. Sandford, and S. J. Grabowski. 1994. Relative survival of subyearling chinook salmon at Bonneville Dam, 1992. Coastal Zone and Estuarine Studies Division of the National Marine Fisheries Service. December 1994. Seattle, Washington. 83 p.

Leider, S.A., P.L. Huelett, J.J. Loch and M.W. Chilcote. 1990. Electrophoretic comparison of the reproductive success of naturally spawning transplanted and wild steelhead trout through the returning adult stage. Aquaculture 88:239-252.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial processes in geomorphology. Dover Publications Inc.,New York. 522 p.

LeVander, L. 1999. Personal communication with Lori LeVander, WDOE.

Levesque, Andy. 1999. King County. Personal communication. Comments on draft hydromodification report submitted to Sue Madsen 17 November 1999.

Levin, H.L., 1981. Contemporary physical geology. Saunders College Publishing, Philadelphia. 579 p.

Lewis, Jack. November 1985. The Birth of EPA in EPA Journal.

Li, H.W., C.B. Schreck, and R.A. Tubb. 1984. Comparison of habitats near spur dikes, continuous revetments, and natural banks for larval, juvenile and adult fishes of the Willamette River. Final Technical Completion Report, Project 373905, Contract 14-08-001-G864. Water Resources Institute, Oregon State University, Corvallis OR. 15 p.

Ligon, F.K., W.E. Dietrich and W.J. Trush. 1995. Downstream ecological effects of dams: a geomorphic perspective. Bioscience 45(3):183-192.

Lisle, T.E., 1986. Effects of woody debris on anadromous salmonid habitat, Prince of Wales Island, southeast Alaska. North American Journal of Fisheries Management 18:1643-1651

Lister, D.B. and R.J. Finnigan. 1997. Rehabilitating off-channel habitat. Chapter 7 of Fish Habitat Rehabilitation Procedures, P.A. Slaney and D. Zaldokas, Eds. Watershed

Restoration Technical Circular No. 9, Watershed Restoration Program, British Columbia Ministry of Environment, Land and Parks, Vancouver, B.C.

Lloyd, D.S. 1987. Turbidity as a water quality standard for salmonid habitats in Alaska. North American Journal of Fisheries Management, 7:34-45.

Lowrance, R. and 12 others. 1997. Water quality functions of riparian forest buffers in Chesapeake Bay watersheds. Environmental Management 21(5):687-712.

Lowrance, R., R. Leonard, and J. Sheridan. 1985. Managing riparian ecosystems to control non-point source pollution. J. Soil and Water Conservation. 1:87-91.

Lucchetti, F. and R. Furstenberg. 1992. Urbanization, habitat conditions and fish communities in small streams of western King County, Washington, USA, with implications for management of wild coho salmon. Proc. 1992 Chinook and Coho Workshop. Western Division of American Fisheries Society.

Lynn, B., 1998. Nearshore Habitat Loss in Puget Sound: Recommendations for Improved Management. Washington Nearshore Habitat Loss Workgroup, Puget Sound/Georgia Basin International Task Force.

MacCrimmon, H. R. and W. H. Robbins. 1975. Distribution of the black basses in North America. In: H. Clepper (editor). National symposium on the biology and management of the centrarchid basses. Tulsa, Oklahoma February 3-6, 1975. Sport Fishing Institute, Washington, D.C.

Malcolm, R.W.R. 1996. Observations on the Influence of Inwater and Riverbank Disturbances upon the Upstream Migration of Adult Coho Salmon (*Oncorhynchus kistuch*) in the Sammamish River, Washington. Muckleshoot Indian Tribe Fisheries Department. Auburn, Washington.

Malcom, R, 2000. Personal communication. E-mail from Roderick Malcom, Senior Fisheries Biologist, Muckleshoot Indian Tribal Fisheries Department to Tom Nelson, King County. May 24 2000.

Malcom, R. 1999, 2000. Rod Malcom (Senior Habitat Biologist) Muckleshoot Indian Tribe personnel communication to John Kerwin Washington Conservation Commission.

Malcom, R. 1999. Personal communication: E-mail from Roderick Malcom, Fisheries Biologist, Muckleshoot Indian Tribe to Sue Madsen (R2 Resource Consultants)

Malcom, R. 1999. Personnel Communication to John Kerwin, Washington Conservation Commission.

Malcom, R.W.R. 1996. Observations on the Influence of Inwater and Riverbank Disturbances upon the Upstream Migration of Adult Coho Salmon (*Oncorhynchus kistuch*) in the Sammamish River, Washington. Muckleshoot Indian Tribe Fisheries Department. Auburn, WA.

Malcom, R.W.R. 1996. Observations on the Influence of Inwater and Riverbank Disturbances upon the Upstream Migration of Adult Coho Salmon (Oncorhynchus kistuch) in the Sammamish River, Washington. Muckleshoot Indian Tribe Fisheries Department, Auburn WA.

Malcom, R.W.R. 1998. Corps of Engineers/Tacoma Public Utilities Fish Passage Site Visit: Copy of Notes and Photographs taken by Rod Malcom, Senior Habitat Biologist, Environmental Division, Muckleshoot Fisheries Department. Unpublished draft report prepared by the Muckleshoot Indian Tribal Fisheries Department, Puyallup, Washington. 20 pp.

Malcom, R.W.R., 1999. Draft – Salmon habitat conditions in Newaukum Creek between the Whitney Hill Bridge at Rkm 1.6 (RM 1.0) and the Green River, King County, Washington. Muckleshoot Indian Tribe Fisheries Department, Auburn WA. 29. p.
Malcom, R.W.R., 1999. Draft – Salmon habitat conditions in Newaukum Creek between the Whitney Hill Bridge at Rkm 1.6 (RM 1.0) and the Green River, King County, Washington. Muckleshoot Indian Tribe Fisheries Department, Auburn WA. 29. p.
Markle, D. F. 1985. Evidence of bull trout X brook trout hybrids in Oregon. pages 58-67 *In* P. J. Howell and D. V. Buchanan (eds.) Proceedings of the Gearhart Mountain bull trout workshop. Oregon Chapter of the American Fisheries Society, Corvallis, Oregon.

Marshall, A. R., C. Smith, R. Brix, W. Dammers, J. Hymer, and L. LaVoy. 1995. Genetic diversity units and major ancestral lineages for chinook salmon in Washington. Washington Department of Fisheries and Wildlife, Olympia.

Martin, D.J., 1999. An Ecosystem Strategy for Restoring Threatened/Endangered Salmon in King County, A Draft Approach. Prepared for the King County Department of Natural Resources.

Maser, C., and J.R. Sedell. 1994. From the forest to the sea, the ecology of wood in streams, rivers, estuaries, and oceans. St. Lucie Press, Delray Beach, Florida.

Master, D. et al. 1997. Des Moines Creek Basin Plan. Developed by the Des Moines Creek Basin Committee.

Mathur, S. 1974. Phthalate esters in the environment: Pollutants or natural products? J. Environ. Quality. 3:189.

Mavros, W., 2000. Personal communication to Laura Blackmore, King County Department of Natural Resources.

May, C.W. 1996. Assessment of cumulative effects of urbanization on small streams in the Puget Sound Lowland Ecoregion: implications for salmonid resource management. P.h.D Dissertation, University of Washington, Seattle, WA. 382 p.

May, C.W., E.B Welch, R.R. Horner, J.R. Karr, and B.W. Mar 1997. Quality indices for urbanization effects in Puget Sound Lowland Streams. Washington State Department of Ecology, Publication No. 98-04.

May, Chris et.al. June, 1997. Quality Indices for Urbanization Effects in Puget Sound Lowland Streams. For the Washington Department of Ecology.

McAllister, Kelly. 2000. Washington Department of Fish and Wildlife, Olympia, Washington. Personal communication.

Meacham, Pam. 2000. Washington Department of Fish and Wildlife, Olympia, Washington. Personal communication.

Megahan, W.F., 1983. Hydrologic effects of clearcutting and wildfire on steep granitic slopes in Idaho. Water Resourc. Res. 19(3):811-819.

Mercer, S.. 2000. Stu Mercer, Fish Hatchery Specialist 3, Icy Creek and Palmer Ponds hatcheries. Washington Department of Fish and Wildlife.

Metro (Municipality of Metropolitan Seattle). 1989. Green-Duwamish Watershed nonpoint action plan, concurrence draft. Prepared for the Washington State Department of Ecology, Olympia, by the King County Metro, Department of Parks, Planning and Resources, Seattle, Washington.

Metro Water Quality Division Technical Report, Soos Creek Drainage Basin Salmonid Habitat Report. Seattle Washington. January 1988.

Metro. 1978. Areawide Water Quality Plan. Municipality of Metropolitan Seattle (Metro). Pursuant to Section 208. Seattle, WA.
Metro. 1985. Duwamish Industrial Nonpoint Source Investigation. Municipality of Metropolitan Seattle (Metro). 205 J Report. Final Report.
Metro. 1988. Water Quality Status Report for Marine Waters, 1987. METRO Publication 171, Seattle, WA.
Metro. 1991. Quality of Local Lakes and Streams, 1989-90 Status Report. Municipality of Metropolitan Seattle (Metro).
Ministry of Environment, Lands, and Parks (MELP). 1998. Inventory methods for pond-breeding amphibians and painted turtle. Standards for components of British Columbia's biodiversity No. 37. Resources Inventory Branch for the Terrestrial Ecosystems Task Force, Resources Inventory Committee, British Columbia, Canada.
Minton, G.R. 1998. Review of water and sediment quality data. Longfellow Creek. Draft report to Seattle Public Utilities 3/13/98. 17 pp.
Mississippi River Commision (MRC) and Boise State University Public History Program Website. 2000. http://www.boisestate.edu/history/mrc/timeline.html
Montgomery, D.R. and J.M. Buffington. 1993. Channel classification, prediction of channel response, and assessment of channel condition. Timber Fish and Wildlife Report TFW-SH10-93-002. 84 pp.
Montgomery, D.R., E.M. Beamer, G.R. Pess, and T.P. Quinn. 1999. Channel type and salmonid spawning distribution and abundance. Canadian Journal of Fisheries and Aquatic Sciences 56:377-387.
Morisawa, M. 1985. Rivers. Longman Group. Ltd. London and New York. 222 p.
Moyle, P. B., W. Li, and B. A. Barton. 1986. The Frankenstein effect: impact of introduced fishes on native fishes in North America. Pages 415-426 In: R. H. Stroud (Ed). Fish culture in fisheries management. American Fisheries Society. Fish Culture Section, Bethesda, Maryland.
Muckleshoot Indian Tribe Fisheries Department (MITFD). 1998 . Letter submitted to the US Army Corps of Engineers Policy Review and Analysis Division, Fort Belevoir, Virginia.
Muckleshoot Indian Tribe. 1992. Water Quality and Quantity Concerns for the Keta Creek Hatchery and Crisp Creek Watershed. Muckleshoot Indian Tribe Fisheries Department. Auburn, WA.
Mullineaux, D.R. 1970. Geology of the Renton, Auburn and Black Diamond quadrangles, King County, WA. USGS Professional Paper 672. 92 p.
Munday, Eric. 1999. Current Watershed Habitat Descriptions, Conditions, and Problem Areas on Vashon-Maury Island. Prepared for King County Department of Natural Resources, Water and Land Resources Division, Central Puget Sound Watershed Team, Seattle, WA.
Myers, J. M., R. G. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F. W. Waknitz, K. Neely, S. T. Lindley, and R. S. Waples. 1998. Status review of chinook salmon from Washington, Idaho, Oregon, and California. U.S. Department of Commerce, NOAA, Seattle.
Naiman, R.J., T. Beechie, L.E. Benda, D.R. Berg, P.A. Bisson, L.H. MacDonald, M.D. O'Connor, P.L. Olsen, and E.A. Steele. 1992. Fundamental elements of ecologically healthy watersheds in the Pacific Northwest Coastal Ecoregion. Pages 127-188 in R.J. Naiman, Ed., Watershed management: balancing sustainability and environmental change. Springer-Verlag, New York.

Nakamura, F. and F.J. Swanson. 1993. Effects of coarse woody debris on morphology and sediment storage of a mountain stream system in western Oregon. Earth Surface Processes and Landforms. 18:43-61.

NAS 1973. Water quality criteria 1972. National Academy of Sciences and National Academy of Engineering. U.S. Environmental Protection Agency Ecological Research Series EPA-R3-73-033.

National Marine Fisheries Service (NMFS). 1999. A guide to biological assessments. Prepared by the National Marine Fisheries Service Washington Habitat Conservation Branch, March 23 1999. Lacey, Washington. 19 p.

National Marine Fisheries Service. 1996. Coastal salmon conservation: working guidance for comprehensive salmon restoration initiatives on the Pacific coast.

National Marine Fisheries Service. 1999. A guide to biological assessments. Prepared by the National Marine Fisheries Service Washington Habitat Conservation Branch, March 23 1999. Lacey, Washington. 19 p.

Natural Resource Consultants. 1995. Development of a Baseline Monitoring Program for Dumas Bay. Prepared for City of Federal Way, Department of Community Development.

Nei, M. 1978. Estimation of average hetreozygosity and genetic distance from a small number of individuals. Genetics 89:583-590.

Nelson, T. 1997. Unpublished South Fork Hamm Creek Reconnaissance Report. King County Department of Natural Resources.

Nelson, T. 2000. Tom Nelson, Senior Ecologist, King County personal communication to John Kerwin, Regional Technical Representative Washington Conservation Commission.

Nelson, T., 2000. Personal communication to Laura Blackmore. King County Department of Natural Resources.

Nelson, Tom. 2000. King County Water Land and Resources Division, Seattle, Washington. Personal communication.

Newcombe, C.P, and J.O.T. Jensen 1996. Channel suspended sediment and fisheries: A synthesis for quantitative assessment of risk and impact. N. Am. J. Fish. Management 16:693-727.

Nielsen, J.L., T.E. Lisle and V. Ozaki. 1994. Thermally stratified pools and their use by steelhead in northern California streams. Trans. Amer. Fish. Soc. 123:613-626.

Niiyama, K. 1990. The role of seed dispersal and seedling traits in colonization and coexistence of Salix species in a seasonally flooded habitat. Ecological Research 5:317-333.

Noble, J. B. 1969. Geohydrologic investigation of the North Fork of Green River valley report submitted to City of Tacoma, prepared by Robertson, Roberts and Associates, Inc. March.

Noble, J. B. and D. K. Balmer. 1978. Hydrologic analysis City of Tacoma North Fork well field. Consultant report prepared for City of Tacoma Department of Public Utilities by Robinson and Noble Inc. 11 pages plus illustrations.

North Fork Newaukum Creek Smolt Trap Report. Mid-Sound Fisheries Enhancement Group. Seattle Washington.

Northwest Indian Fisheries Commission. 1994. Ambient Monitoring Program Manual. TFW-AM9-94-001. Olympia, WA.

O’Connor, M. 1996. Hydrology; Section 4C Lester Watershed Analysis. Prepared by Plum Creek for Washington Department of Natural Resources.

O’Connor, M. 1997. Cannel Condition; Section 4E Upper Green/Sunday Watershed Analysis. Prepared by Plum Creek for Washington Department of Natural Resources. 33 p DRAFT

Oakley, A.L.; Collins, J.A.; Everson, L.B.; Heller, D.A.; Howerton, J.C. and Vincent, R.E. 1985. Riparian zones and freshwater wetlands. P.57-80 Brown, E.R., tech. ed., Management of Wildlife and Fish Habitats Forests of Western Oregon and Washington. R6-F&WL-192-1985. USDA Forest Service and USDI Bureau of Land Management, Portland.

Olson, John 1999. USACE Howard Hanson Dam Project Operator. Personal communication. Telephone conversation with Phil Hilgert, R2 Resource Consultants, 2 April 1999.

Osborne, L.L. and D.A. Kovavic. 1993. Riparian vegetated buffer strips in water quality restoration and stream management. Freshwater Biology 29:243-258.

Pacific Groundwater Group. 1999. 1999 Hydrogeologic characterization, City of Auburn. Consultant report prepared for The City of Auburn Department of Public Works, Auburn, Washington.

Parametrix. June, 2000. Factors Affecting Chinook Populations. Produced for the City of Seattle.

Parkinson, E.A. 1984. Genetic variation in populations of steelhead trout (*Salmo gairdneri*) in British Columbia. Can. J. Fish. Aquat. Sci. 41:1412-1420.

Paustain, S.J., K. Anderson, D. Blanchet, S. Brady, M. Cropley, J. Edgington, J. Fryxell, G. Johnejack, D. Kelliher, M. Kuehn, S. Maki, R. Olson, J. Seesz and M. Wolanek. 1992. A channel type users guide for the Tongass National Forest, Southeast Alaska. U.S. forest Service, Alaska Region R10-TP-26. 179 p.

Pence, W.R. 1946. The White River Valley of Washington, M.A. Thesis, University of Washington, Seattle WA.

Pentec 1999. Unpublished Draft report on Shoreline Habitat in the lower Green/Duwamish River. 4 p.

Pentec Field Survey. 1999. Unpublished field survey notes and photographs. May 1999. Pentec Environmental, Edmonds, Washington.

Pentec. 1999. Draft Water Quality Trends Report for the Green/Duwamish Watershed.

Penttila, D.E., 2000. Impacts of overhanging shading vegetation on egg survival for summer-spawning surf smelt, *Hypomesus*, on upper intertidal beaches in northern Puget Sound, WA. Washington Department of Fish and Wildlife, Marine Resources Division, La Connor, Washington, Draft Briefing Report.

Perkins, S. 1998. Geomorphic feasibility report for Flaming Geyser Landslide. Unpublished consultant report prepared for King County. Perkins Geosciences, Seattle WA. 8 p.

Perkins, S. J. 1993. Green River Channel Migration Study. King County Department of Public Works, Surface Water Management Division, Seattle WA.

Perkins, S. J.. 1999. Geomorphic Feasibility Report for Burns Creek.

Perkins, S.J. 1993. Green River channel migration study. King County Dept. Public Works, Surface Water Management Division. Seattle WA. 45 p.

Perkins, S.J. 1993. Green River channel migration study. Prepared by King County Department of Public Works Surface Water Management Division River Management Section. Seattle, WA. December 1993. 45pp.

Perkins, S.J. 1999. Geomorphic feasibility report for large woody debris placement in the middle Green River, Washington. Prepared for Jones & Stokes Associates, Inc. and U.S. Army Corps of Engineers, Seattle District. Perkins Geosciences, Seattle, WA. 29 p.

Perkins, S.J. 2000. Geomorphic evaluation of gravel placement in the Green River, Washington. Prepared for Jones & Stokes Associates, Inc and U.S. Army Corps of Engineers, Seattle District. Perkins Geosciences. 52 p.

Peters, R.J., B.R. Missildine, D.L. Low. 1998. Seasonal fish densities near river banks stabilized with various stabilization methods. U.S. Fish and Wildlife Service, Lacey, WA. 34 p.

Peters, R.J., E.E. Knudsen, C.J. Cederholm, W.J. Scarlett, and G.B. Pauley. 1993. Preliminary results of woody debris use by juvenile coho salmon (*Onchorhynchus kisutch*) in the Clearwater River, Washington. Pages 323-329 in Proceedings of the coho salmon workshop. Sponsored by the Association of Professional Biologists of British Columbia and the North Pacific International Chapter of the American Fisheries Society, Nanaimo, British Columbia

Peterson, D.R., A. Livingston, and J.H. Behlke. 1955. An investigation of pollution in the Green-Duwamish River. Washington State Department of Ecology, Pollution Control Commission, Technical Bulletin 20, Olympia, WA.

Peterson, N.P. 1982. Population characteristics of juvenile coho salmon (*Onchorhynchus kisutch*) overwintering in riverine ponds. Canadian Journal of Fisheries and Aquatic Sciences 39:1303-1307.

Pfeifer, Robert. 2000. Parametrix, Kirkland, Washington. Personal communication.

Phelps, S., J Uehara, D. Hendrick, J. Hymer, A. Blakley, and R. Brix. 1995. Genetic diversity units a major ancestral lineages for chum salmon in Washington. Washington State Department of Fish and Wildlife. Olympia, WA.

Piper, R., I. B. McElwain, L. E. Orme, J. P. McCraren, L.G. Fowler and J. R. Leonard. 1982. Fish hatchery management. United States Department of Interior, U. S. Fish and Wildlife Service.

Plum Creek Timber Company, L.P. (Plum Creek). 1996. Lester Watershed Analysis. Report prepared by Plum Creek for Washington Department of Natural Resources.

Plum Creek Timber Company, L.P. (Plum Creek). 1997. Upper Green/Sunday Watershed Analysis. Report prepared by Plum Creek for Washington Department of Natural Resources. DRAFT.

Poff, L. N., J. D. Allan, M. B. Bain, J.R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47(11) 769-784.

Port of Seattle. 1993. Aerial photos of the Duwamish Waterway and Elliott Bay. Photos No. KIN0048 to KIN 0129. Port of Seattle, Washington.

Port of Seattle. 1993. Unpublished aerial photographs of Elliott Bay from West Point to Alki Point and the Duwamish River from Kellogg Island to the mouth. Port of Seattle, Seattle, Washington.

Port of Seattle. 1994. South Aviation Support Area Final EIS.

Port of Seattle. Unpublished. Shoreline habitat data. Elliott Bay and Duwamish Estuary. Port of Seattle, Seattle, Washington.

Prothro, M.G. 1993. Office of water policy and technical guidance on interpretation and implementation of aquatic metals criteria. Memorandum from Acting Assistant Administrator for Water. Washington D.C. U.S. EPA Office of Water. 7 pp. Attachments 41 pp.

Puget Sound Regional Council (PSRC). 1998. 1998 Regional Review: Monitoring Change in the Central Puget Sound Region.

Pyrch, E.A., D.L. Kresch, J.C. Ebbert and G.L. Turney. 1995. Data and statistical summaries of background concentrations of metals in soils and streambed sediments in part of Big Soos creek drainage basin, King County, Washington. U.S. Geological Survey. Water Resources Investigations Report 94-4047. 81 pps.

R2 2000; USFS 1998; Watson and Hillman 1997; Goetz 1998 [Tacoma HCP]

R2 Consulting. February, 2000. Tri-County Urban Issues Study.

R2 Resource Consultants, Inc. 1998. Annotated bibliography of literature regarding the mechanical injury of fish in spillways and stilling basins – revised draft report. Report prepared for the U.S. Army Corps of Engineers, Portland District. Contract No. DACW57-96-D-007.

Reiman, B. E., R. C. Beamesderfer, S. Vigg, and T. P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Trans. Am. Fish. Soc. 120:448-458.

Renton, City of. 1993. Black River Basin Draft Water Quality Management Plan. Prepared by R.W. Beck and Associates and Herrera Environmental Consultants. Renton, WA.

Richter, B. D., J. V. Baumgartner, J. Powell and D. P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10(4):1163-1174.

Riseland, J.. 1913. Twenty-Second and Twenty-Third Annual Reports of the State Fish Commissioner and Ex-Officio Game Warden to the Governor of the State of Washington. Jno. L. Riseland, Commissioner and Ex-Officio Game Warden. Department of Fisheries and Game, State of Washington.

Robinson J. W. 1974. Principal, Robinson and Noble Inc., Ground Water Geologists. Personal communication. Letter to John Roller, Water Division Superintendent, City of Tacoma Department of Public Utilities. 13 May.

Robinson, J. W. 1970. Results of additional studies on the ground-water underflow of the North Fork of the Green River. Consultant report prepared for the City of Tacoma. Robinson, Roberts & Associates, Inc., Tacoma, Washington. Eight pages plus illustrations and appendix.

Rogers, J.S. 1991. A comparison of the suitability of the Rogers, modified Rogers, Manhatten and Calalli-Sforza and Edwards distances for inferring phylogenetic trees from allele frequencies. Syst. Zool. 40:63-73.

Ryan, D. J. 1999. Dick Ryan, Watershed Forester, Tacoma Public Utilities. Personnel communication with Sue Madsen (R2 Resource Consultants). 8 April 1999.

Saitou, N. and M. Nei. 1987. The neighbor joining method: a new method for reconstructing phylogenetic trees. Molecular Biology and Evolution 4:406-425.

SalmonWeb, 2000. Volunteer Report – 1999 Biological Monitoring Data. SalmonWeb, Seattle, WA.

Salo, E.O. 1969. Final report for the period June 1, 1965 – September 30, 1968, Estuarine Ecology Research Project. Univ. of Washington, Fisheries Research Institute Report. Seattle, WA.

Salo, E.O. 1991. Life History of chum salmon. Pages 231-309 in C. Groot and L. Margolis, Eds., Pacific Salmon Life Histories. U.B.C. Press, Vancouver, B.C.

Santos, J.F. and J.D. Stoner. 1972. Physical, chemical, and biological aspects of the Duwamish River estuary, King County, Washington 1963-67. USGS Water Supply Paper, 1873-C.

Sawtooth National Recreation Area, Sawtooth National Forest (SNF). 1994a. Risks to, and Protection Efforts for, Snake River Spring/Summer Chinook (*Oncorhynchus tshawytscha*) within the Main Salmon River Canyon, 1994. USDA Forest Service. Report. Stanley. Idaho.

Sawtooth National Recreation Area, Sawtooth National Forest (SNF). 1994b. Implementation of the Incidental Take Statement for Snake River Spring/Summer Chinook (*Oncorhynchus tshawytscha*) Associated with 1994 Recreational Floatboating on the Main Salmon River. USDA Forest Service. Monitoring Report. Stanley. Idaho.

Sawtooth National Recreation Area, Sawtooth National Forest (SNF). 1994c. Floatboating Activities on the Upper Main Salmon River. USDA Forest Service. Biological Assessment. Stanley. Idaho.

Sawtooth National Recreation Area, Sawtooth National Forest (SNF). 1994d. Floatboating Activities on the Main Salmon River for Snake River Sockeye Salmon and Snake River Spring/Summer Chinook Salmon. USDA Forest Service. Supplemental Biological Assessment to the 1992 Biological Assessment. Stanley. Idaho.

Scarey, Michael. 1994. Land Use Change in the Lower Green River Valley 1965-1989: Toward Developing a Method for Monitoring Growth Management. Masters Thesis. University of Washington.

Schaefer, et. al. 2000. Lower Green River Levee and Revetment Repairs, Construction Year 2001, Batched Biological Assessment for Puget Sound Chinook and Coho Salmon, Bull Trout and Bald Eagle. King County Department of Natural Resources, Water and Land Resources Division, Rivers Section, Seattle, WA.

Schaeffer, Ruth. 2000. King County Water and Land Resource Division, Seattle, Washington. Personal communication.

Schneider, P. 2000. Phil Schneider (Area Habitat Biologist) Washington Department of Fish and Wildlife personnel communication to John Kerwin Washington Conservation Commission.

Schreck, C.B., H.W. Li, R.C. Hjort, and C.S. Sharpe. 1986. Stock identification of Columbia River chinook salmon and steelhead trout. Final Report 83-541, Bonneville Power Administration, Portland, OR 184 pp.

Schuett-Hames, D., A.E. Pleus, J. Ward, M. Fox and J. Light. 1999. TFW Monitoring Program method manual for the large woody debris survey. Prepared for the Washington State Department of Natural Resources under the Timber, Fish and Wildlife Agreement. TFW-AM9-99-004. DNR #106. 32 p. + Appendices

Schuett-Hames, J.P., and D.E. Schuett-Hames. 1984. Spawning gravel fine sediment levels and stream channel stability in the Nooksack basin, Washington, 1982and 1983. Lummi Tribal Fisheries Departments. Lummi Fisheries Department, Bellingham WA. 26 p,

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Ottawa, Canada.

Seattle King County Health Department. 1995. Draft Vashon-Maury Island Ground Water Management Plan Supplement: Area Characterization. Developed by: Vashon-Maury Island Ground Water Advisory Committee. Lead Agency: Seattle-King County Health Department, Environmental Health Division, Ground Water Section.

Sedell, J.R. and J.L. Froggatt 1984. Importance of streamside forests to large rivers: the isolation of the Willamette River, Oregon, USA from its floodplain by snagging and streamside forest removal. Verh. Internat. Verein. Theor. Ange. Limnol. 22:1828-1834.

Seidel, P. 1983. Spawning Guidelines for the Washington Department of Fisheries Hatcheries. Washington Department of Fisheries. Olympia.

Seiler, D. 2000. Dave Seiler Washington Department of Fish and Wildlife personal communication to John Kerwin (Washington Conservation Commission).

Seiler, D. and S. Neuhauser. 1985. Evaluation of downstream migrant passage at Howard Hanson Dam, Green River. *In* Evaluation of downstream migrant passage at two dams: Condit Dam, Big White Salmon River, 1983 and 1984; Howard Hanson Dam, Green River, 1984. Washington Department of Fisheries, Progress Report No. 235, Olympia, Washington. 94 p.

Seiler, D., S. Wolthausen and L.E. Kishimoto. 1991. Evaluation of downstream migrant passage through the sediment retention structure, North Fork Toutle River, 1991. Washington Department of Fisheries Olympia, Washington.

Shapiro and Associates Inc. 1990. The Mill Creek drainage basin: an historical overview of the lower Green River. Consultant report prepared for PTI Environmental Services for submittal to the U.S. Army Corps of Engineers Seattle District, Seattle WA. 95 p.

Shapiro and Associates, Inc. 1985. Aquatic habitat and vegetation survey for Howard Hanson Dam, Washington.

Shapiro and Associates. 1987. Lakota Creek Relocation, Preliminary Stream and Landscape Construction and Monitoring Report. January 1987.

Shoemaker, A. 2000. Ann Shoemaker (City of Seattle) personnel communication to John Kerwin (Washington Conservation Commission).

Simenstad, C.A. and J.R. Cordell. 2000. Ecological assessment criteria for restoring salmonid habitat in Pacific Northwest estuaries. Ecological Engineering 15:283-302.

Simenstad, C.A. and R.M. Thom. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecological Applications 6(1):38-56.

Simenstad, C.A., 1999. Commencement Bay Aquatic Ecosystem Assessment: Ecosystem-scale restoration for juvenile salmonid recovery (Final Review Draft). Prepared for the City of Tacoma, Washington Department of Natural Resources, and the U.S. Environmental Protection Agency.

Smalley, E.V. 1883. History of the Northern Pacific Railroad. G.P. Putnam and Sons, New York, NY.

Smith, David C. and Associates. 1994. Maps depicting the Middle Green River floodplain, Sheets 1 through 9, Green River, King County Washington. Job 1159A. Portland, Oregon.

Smith, L.S., J.B. Saddler, R.C. Cardwell, A.J. Mearns, H.M. Miles, T.W. Newcomb, and K.C. Watters. 1971. Responses of teleost fish to environmental stress. EPQ Report No. 18050 EBK. Fed. Water Qual. Admin. 116 pp.

Soil Conservation Service. 1985. Hydric soils of the state of Washington. Published in cooperation with the National Technical Committee for Hydric Soils. United States Department of Agriculture

South King County Ground Water Advisory Committee (SKCGWAC). 1989. South King County Ground Water Management Plan, Volumes I and II.

Spence, B.C., G.A Lomnicky, RM. Hughes, R.P. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, OR.

Starstead, J. 2000. Seattle Public Utilities. Personal communication reported to J. Kerwin via Ann Shoemaker (Seattle Public Utilities).

Strahan, J. 1984. Regeneration of riparian forests of the Central Valley. Pages 58-67 in R.E. Warner and K.M. Hendris, Eds., California riparian ecosystems. University of California Press, Berkley, CA.

Sullivan, K., J. Tooley, K. Doughty, J.E. Caldwell, and P. Knudsen. 1990. Evaluation of prediction models and characterization of stream temperature regimes in Washington. Timber/Fish/Wildlife Rep. No. TRW-WQ3-90-006. Washington Department of Natural Resources, Olympia, WA. 224pp.

Sullivan, K., J. Tooley, K. Doughty, J.E. Caldwell, and P. Knudsen. 1989. Evaluation of prediction models and characterization of stream temperature regimes in Washington. Timber/Fish/Wildlife Report No. TFW-5002/89/2. Tacoma, Washington. 54 p.

Swift, C.H. 1979. Preferred stream discharges for salmon spawning and rearing in Washington. Open-File Report 77-422. U.S. Geological Survey, Tacoma, WA.

Sylvester, R.G., G.T. Orlob, A. Young, W. Montgomery, and L.S. Orlob. 1949. A survey of Puget Sound pollution: Seattle metropolitan area. Washington State Department of Ecology, Pollution Control Commission, Olympia, WA.

Tacoma Public Utilities (Tacoma). 1999. Tacoma Water habitat conservation plan: Green River water supply operations. Public Review Draft-December 1999. Tacoma Public Utilities, Tacoma Water. Tacoma, Washington.

Tacoma Public Utilities (TPU). November 1998. Tacoma Water and the Green River Watershed. TPU Public Outreach Pamphlet.

Tacoma Public Utilities. 1999. Tacoma Water Habitat Conservation Plan. Tacoma, WA.

Tanner, C.D. 1991. Potential intertidal habitat restoration sites in the Duwamish River estuary. Prepared for the Port of Seattle Engineering Department and US Environmental Protection Agency, EPA 910/9-91-050, Seattle, Washington.

Tappel, P.D., and T.C. Bjornn. A new method of relating size of spawning gravel to salmonid embryo survival. N. Amer. J. Fish. Manag. 3:123-135.

Taylor, W., 2000. Personal communication to Laura Blackmore. King County Department of Natural Resources.

Thomas, B.P. and R.H. Thompson 1936. Inter-county river improvement. Annual report of the engineers. Huntley and Rowe Inc., Tacoma WA. 31 p.

Thomas, J. W. 1979. Wildlife habitats in managed forests. Washington, D. C.: USDA Forest Service (Agricultural Handbook No. 533).

Thomas, T. 1999. Crown diameters for coniferous and deciduous species found in coastal and Cascade Mountains. Unpublished table prepared by Ted Thomas, U.S. Fish and Wildlife Service, Olympia Washington. November 1999.

Toth, S., P. Reynolds, C. Coho, M. O'Connor, K. Doughty, M. Fox, E. Cupp, J. Metzler, M. O'Connor, G. Laurie, and D. Ellison. 1996. Lester Watershed Analysis. Plum Creek Timber Company. Seattle, WA.

Toth, S., P. Reynolds, F. Krogstad, S. Evans, P. Wetherbee, H. Ehlert, M. Fox, G. Watson, M. O'Connor, K. Gonce, G. Ketcheson, D. Ryan, B. King, C. Frame, and C. Moya. 1997 Draft. Upper Green-Sunday Watershed Analysis. Plum Creek Timbre Company. Seattle, WA.

Troendle, C.A. and R.M. King, 1985. The effect of timber harvest on the Fool Creek Watershed, 30 years later. Water Resourc. Res. 21(12):1915-1922.

U.S. Army Corps of Engineers (USACE). 1905. Duwamish River, Washington. Map compiled under the direction of Lt. FA. Pope.

U.S. Army Corps of Engineers (USACE). 1907. Duwamish-Puyallup Surveys, Sheets 11-15 and Sheet 30.

U.S. Army Corps of Engineers (USACE). 1944. Aerial photographs. University of Washington Map Files.

U.S. Army Corps of Engineers (USACE). 1979. Howard A. Hanson Dam. U.S. Army Corps of Engineers, North Pacific Division, Seattle District, Seattle, WA.

U.S. Army Corps of Engineers (USACE). 1994. Howard Hanson Dam reservoir sedimentation (1979 resurvey). Report produced by the U.S. Army Corps of Engineers Seattle District, Seattle WA. 11 p.

U.S. Army Corps of Engineers (USACE). 1995. Howard Hanson Dam draft environmental impact statement for operation and maintenance. December.

U.S. Army Corps of Engineers (USACE). 1997. Green/Duwamish River Basin. General investigation ecosystem restoration study reconnaissance phase. January 1997. Seattle, WA. ~180 p.

U.S. Army Corps of Engineers (USACE). 1998. Additional water storage project, final feasibility report & EIS. Howard Hanson Dam, Green River, Washington. Executive summary. August 1998. Seattle, WA. 74 p + appendices.

U.S. Army Corps of Engineers (USACE). 1998. Howard Hanson Dam additional water storage project. Draft Feasibility Report and Environmental Impact Statement. U.S. Army Corps of Engineers, Seattle District, Seattle WA.

U.S. Army Corps of Engineers (USACE). 1998. Howard Hanson Dam additional water storage project. Draft Feasibility Report and Environmental Impact Statement. U.S. Army Corps of Engineers, Seattle District, Seattle WA.

U.S. Army Corps of Engineers, Seattle District (USACE). 1997. Howard A. Hanson Dam final environmental impact statement for operation and maintenance. January 1997. Seattle, WA. ~50 p.

U.S. Army Corps of Engineers, Seattle District (USACE). 1998. Appendix F, Environmental Part 1, Fish Mitigation and Restoration. Additional Water Storage Project, draft feasibility report and EIS, Howard A. Hanson Dam, Green River, Washington. April 1998. Seattle, WA

U.S. Army Corps of Engineers. 1995. Howard Hanson Dam Draft EIS for Operation and Maintenance. Seattle, WA.

U.S. Army Corps of Engineers. 1997. Green/Duwamish River Basin: general investigation ecosystem restoration study, reconnaissance phase. US Army Corps of Engineers, Seattle District, Seattle, WA.

U.S. Department of Transportation, Federal Aviation Administration and Port of Seattle. 1996. Final Environmental Impact Statement for Proposed Master Plan Update Development Actions at Seattle-Tacoma International Airport. Volume 1 of 7, Chapters I through VI, Appendices A-B.

U.S. EPA 1980a. Ambient water quality criteria for polynuclear aromatic hydrocarbons (PAHs). EPA 440/5-80-069. U.S. Environmental Protection Agency, Office of Water, Washington D.C.

U.S. EPA 1980b. Ambient water quality criteria for acenaphthene. EPA 440/5-80-015. U.S. Environmental Protection Agency, Office of Water, Washington D.C.

U.S. EPA 1980c. Ambient water quality criteria for phthalate esters. EPA 440/5-80-057. U.S. Environmental Protection Agency, Office of Water, Washington D.C.

U.S. EPA 1986. Quality criteria for water, 1986. EPA 440/5-86-001. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

U.S. EPA 1988. Ambient water quality criteria for aluminum. EPA 440/5-86-008. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

U.S. EPA 1993. Water quality criteria: aquatic life criteria for metals. Federal Register 58(108):32131–32133.

U.S. EPA 1998. 1998 update of ambient water quality criteria for ammonia. EPA 822-R-98-008. U.S. Environmental Protection Agency, Office of Water, Washington D.C.

U.S. EPA 1999. 1999 update of ambient water quality criteria for ammonia. EPA 822-R-99-014. U.S. Environmental Protection Agency, Office of Water, Washington D.C.

U.S. EPA. 1976. Quality criteria for water 1976. Office of Water and Hazardous Materials, Washington, DC. GPO #055-001-01049-4.

U.S. EPA. 1991. Technical suport document for water quality-based toxics control. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA 505/2-90-001.

U.S. Forest Service (USFS). 1996. Green River watershed analysis. Final Report plus Appendices A-H. Mt. Baker-Snoqualmie National Forest, North Bend Ranger District. 492 p.

U.S. Forest Service. 1996. Green River Watershed Analysis. Prepared by the US Department of Agriculture USFS Mt. Baker-Snoqualmie National Forest, North Bend Ranger District.

U.S. Geological Survey (USGS). 1996. Water Resources Data Washington Water Year 1996. U.S. Geological Survey Water-Data Report WA-96-1. Department of Commerce, NTIS Springfield, VA.

U.S. Geological Survey (USGS). Data provided by Luis Fuste, Information officer, U.S. Geological Survey. May 2000.

U.S. Geological Survey 1900. Land Classification Sheet, Washington, Tacoma Quadrangle. Land classification by J.W. Rankine and G.H. Plummer Surveyed in 1897. 1900 Edition.

United States Army Corps of Engineers (USACE). 1997. Green/Duwamish River Basin: General Investigation Ecosystem Restoration Study Reconnaissance Phase.

United States Census Bureau Website. 2000. Population Estimates. (http://www.census.gov/population/www/estimates/popest.html).

United States Forest Service (USFS). 1996. Green River watershed analysis. Final Report plus Appendices A-H. Mt. Baker-Snoqualmie National Forest, North Bend Ranger District. 492 p.

Unknown Author. 1988. Mill creek basin study. Final Report. Green River Basin Program.

Utter, F., G. Milner, G. Stahl, and D. Teel. 1989. Genetic population structure of chinook salmon (Oncorhynchus tshawytscha), in the Pacific Northwest. *Fisheries Bulletin* 85: 13-23.

Utter, F.M., D. Campton, S. Grant, G.B. Milner, J. Seeb, and L. Wishard. 1980. Population structures of indigenous salmonid species in the Pacific Northwest. In: W.J. McNeil and D.C. Himsworth (Editors), Salmonid Ecosystems of the North Pacific. Oregon State University Press and Oregon State University sea Grant College Program, Corvallis, OR. pp. 285-304.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. 40:452-461.

Vashon-Maury Island Land Trust. 1999. Shinglemill Creek Monitoring Report.

Wachter, H. M. 1999. Newaukum Creek Basin Stormwater Sampling Report, Water Years 1995-97. King County Water and Land Resources Division.

Walton, S.P. 1996. Aquatic Plant mapping for 36 King County Lakes. Final Report Grant N. G9500310. Funded in part by the Washington Department of Ecology.

Waples, R. S. 1991. Definition of “species” under the Endangered Species Act: application to pacific salmon. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-194.

Warner, E. 1996. Travel time of coho and chinook salmon and steelhead trout smolts emigrating through Howard Hanson Reservoir, King County,Washington: an analysis of mobile tracking and fixed receiver data. Muckleshoot Indian Tribe Fisheries Department draft document. Muckleshoot Indian Tribe, Auburn Washington19 pp. + Appendices.

Warner, E. 2000. Personal communication with Eric Warner, Biologist, Muckleshoot Indian Tribe Fisheries Department. Conversation with S. Madsen and P. Hilgert, 17 March 2000.

Warner, E.J., and R.L. Fritz. 1995. The distribution and growth of Green River chinook salmon (*Oncorhynchus tshawytscha*) and chum salmon (*Oncorhynchus keta*) outmigrants in the Duwamish Estuary as a function of water quality and substrate. Muckleshoot Indian Tribe, Auburn, Washington.

Warren, James R., King County and its Emerald City. (Seattle: The Museum of History and Industry/ American Historical Press, 1997)

Washington Aquatic Nuisance Planning Committee (WANSPC). 1998. Washington state aquatic nuisance management plan, prepared by the Washington Aquatic Nuisance Planning Committee, chaired by S. S. Smith, Washington Department of Fish and Wildlife.

Washington Department of Ecology (Ecology). 1998. Department of Ecology decision matrix for surface waters listed under section 303(d) included in 305B report of the Federal Clean Water Act (CWA). Ecology, Olympia, Washington.

Washington Department of Ecology (WDOE) 1995. Initial watershed assessment: Water Resources Inventory Area 9, Green-Duwamish watershed. WA Department of Ecology Open-File Report 95-01, Bellevue WA. 52 p.

Washington Department of Fish and Game (WDFG). 1920. Thirtieth and thirty-first annual reports.

Washington Department of Fish and Wildlife (WDFW) and Western Washington Treaty Indian Tribes (WWTIT). 1994. 1992 Washington State salmon and steelhead stock inventory, Appendix 1 Puget Sound stocks. WDFW, Olympia, Washington.

Washington Department of Fish and Wildlife (WDFW). 1999. (Web site) Warmwater fish of Washington. Available at <http://www.wa.gov/wdfw/outreach/fishing/warmwater.htm>.

Washington Department of Fish and Wildlife (WDFW). 2000. (Web site) 2000 catchable trout plants. Available at <http://www.wa.gov/wdfw/fish/regions/reg4/reg4.htm>.

Washington Department of Fish and Wildlife (WDFW). 2000b. (Web site) WDFW fact sheets: green crabs. Available at <http://www.wa.gov/wdfw/ish/shelfish/greencrb.htm>.

Washington Department of Fish and Wildlife and Western Washington Treaty Tribes. 1994. 1992 Salmon and Steelhead Stock Inventory Report.

Washington Department of Fisheries, Progress Report No. 235. Olympia, WA. 94 p.

Washington Forest Practice Board. 1993, 1994. Standard Methodology for Conducting a Watershed Analysis under Chapter 222-22 WAC, version 2.0, 2.1.

Washington Forest Practices Board (WFPB). 1997. Standard methodology for conducting watershed analysis. Version 4.0. Department of Natural Resources, Forest Practices Division, Olympia, WA.

Washington Forest Practices Board (WFPB). 2000. Forest and Fish Emergency Rule manual. Distributed at training session February 2000.

Washington Forest Practices. Board Manual: Standard Methodologies for Conducting Watershed Analysis Under Chapter 222-22 WAC Version 3.0 November 1995.

Washington State Department of Ecology (WDOE) Website, 2000. Background: Washington's Shoreline Management Act (http://www.ecy.wa.gov/programs/sea/SMA/backgroun.htm).

Washington State Department of Ecology, 1988. Draft nonpoint source pollution management program. Ecology, Olympia, WA.

Washington State Department of Natural Resources (WSDNR). 1995. Our Changing Nature: Natural Resource Trends in Washington State.

Washington State Office of Financial Management (OFM) Web Site 2000. Federal Census Decennial Population Counts for the State, Counties and Cities 1890 to 1990 (http://www.ofm.wa.gov/pop189090/pop189090.xls).

WDF, WDW, and WWTIT (Washington Department of Fisheries, Washington Department of Wildlife, and Western Washington Treaty Indian Tribes. 1993. 1992 Washington state salmon and steelhead stock inventory (SASSI). Wash. Dep. Fish Wildl., 212 p. + three appendices. Appendix 1: Hood Canal and Strait of Juan de Fuca (December 1994, 424 p.), North Puget Sound (June 1994, 418 p.), and South Puget Sound (September 1994, 371 p.) volumes. Appendix 2: Coastal stocks (August 1994, 587 p.). Appendix 3: Columbia River stocks (June 1993, 580 p.). Wash. Dep. Fish Wildl., P.O. Box 43151, Olympia, WA 98504.

WDFW 1999a. Spawning Ground Survey Database. A historical database of spawning ground surveys maintained by WDFW.

WDFW and WWTIT. 1994. Salmon and Steelhead Stock Inventory (SASSI). Appendix 1. Puget Sound Stocks. South Puget Sound Volume. Olympia, Washington.

Weis, P., J.S. Weis, and T. Proctor. 1993. Copper, chromium, and arsenic in estuarine sediments adjacent to wood treated with chromated-copper-arsenate (CCA). Estuarine, Coastal, and Shelf Science 36:71-79.

Weitkamp, D.E. and R.F. Campbell. 1980. Port of Seattle terminal 107 fisheries study. Document number 80-1229-026. Report prepared for the Port of Seattle by Parametrix Inc. Seattle Washington. 53 pages.

Weitkamp, D.E. and T.H. Schadt. 1982. 1980 Juvenile Salmonid Study. Document No. 82-0415-012F. Report from Parametrix, Inc.. Prepared for the Port of Seattle. Seattle Washington. 42 pages and appendices.

Weitkamp, L.A., T.C. Wainwright, G.J. Bryant, G.B. Milner, D.J. Teel, R.C. Kope, and R.S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. Technical Memorandum NMFS-NWFSC-24. U.S. Department of Commerce, NOAA, Seattle.

Wendt, P. H., R. F. Van Dolah, M. Y. Bobo, T. D. Mathews, and M. V. Levisen. 1993. A study of wood preservative leachates from docks in an estuarine environment. Marine Resources Division, South Carolina Department of Natural Resources, CHP Task Number 03-1.17.

Wenger, S. 1999. A review of the scientific literature on riparian buffer width, extent and vegetation, Revised Edition: March 5 1999. Report produced for the Office of Public Service and Outreach, Institute of Ecology, University of Georgia, Athens Georgia.

West Group 1998. Selected Environmental Law Statutes: 1998-99 Educational Edition. West Group. St. Paul, Minn.

Wetherall, J.A. 1971. Estimation of survival rates for chinook salmon during their downstream migration in the Green River, Washington. Ph.D. Thesis. University of Washington, Seattle, Washington. 169pp.

Wetherbee, P. 1997. Hydrology; Section 4C Upper Green/Sunday Watershed Analysis. Prepared by Plum Creek for Washington Department of Natural Resources.

Wharton, C., D.B. Locke, E. Babcock, B. Erickson, and M. Boule. 1990. The Mill Creek Drainage Basin: an historical overview of the lower Green River Valley. Prepared by Shapiro and Associates, Inc. for PTI Environmental Services. Submitted to the U.S. Army Corps of Engineers, Seattle District. 18 May 1990. 95 p.

Williams, G.D., and Thom, R., 2000. White Paper: Development of Guidelines for Aquatic Habitat Protection and Restoration – Marine and Estuarine Shoreline Modification Issues (Review Draft). Prepared for the Washington State Department of Transportation, the Washington Department of Fish and Wildlife, and the Washington Department of Ecology.

Williams, G.D., et al., In Preparation. The State of the Nearshore Ecosystem: Eastern Shore of Central Puget Sound, Including Vashon and Maury Islands (WRIAs 8 and 9) (Revised Comment Draft). Prepared for the King County Department of Natural Resources.

Williams, R.W., R.M. Laramie and J.J. Ames. 1975. A catalog of Washington streams and salmon utilization. Washington State Dept. of Fisheries, WRIA-09. 34 pp.

Wilson, M. 1999. Mike Wilson, Hatchery Specialist 4, Soos Creek Hatchery, Washington Department of Fish and Wildlife personal communication to John Kerwin, Regional Technical Representative, Washington Conservation Commission.

Wilson, Mike. 2000. WDFW Soos Creek Fish Hatchery, Auburn, Washington. Personal communication.

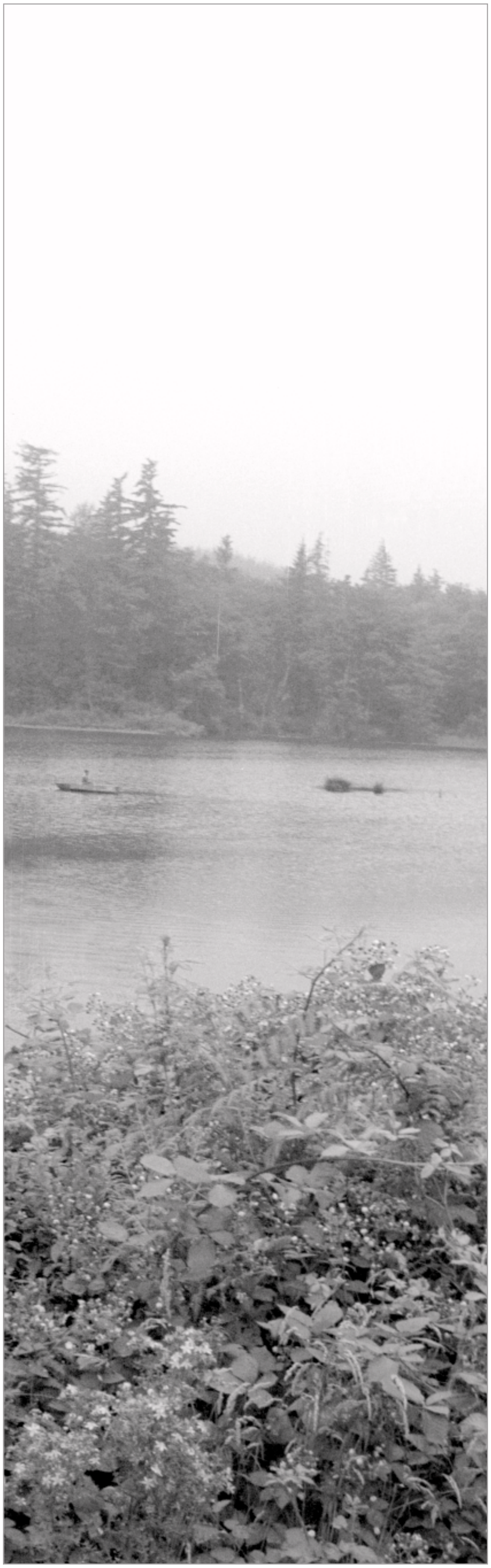
Wissmar, R.C., and Simenstad, C. A., 1998. Chapter 6: Variability of riverine and estuarine ecosystem productivity for supporting Pacific salmon. *In* Change in Pacific Northwest Coastal Ecosystems. http://www.pncers.org/changeinecosystems.htm.

Wood, C.M. 1992. Flux measurements as indices of H+ and metal effects on freshwater fish. Aquat Toxicol 22:239-264.

WSDOE. 2000. Washington Department of Ecology WebSite, Final 303(d) list. 338 pages.

Wunderlich, R. and C.M. Toal. 1992. Potential effects of inundating salmonid tributary habitat due to increased impoundment at Howard Hanson Dam. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia.

Yake, W.E. 1985. Impacts of Western Processing on water quality in Mill Creek (Kent, WA) Department of Ecology, Publication No. 85-e31.



PART V
APPENDIX

Fish Distribution Maps

NOAA ESU Maps

Land Use Tables

Habitat Limiting Factors Matrix

Chinook Life History Report